

The oculomotor system

Or
Fear and Loathing at the Orbit

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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.

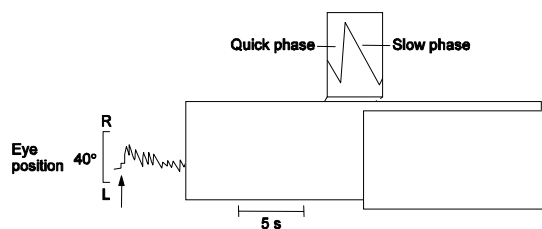
The purposes of eye movements

- Keep an object on the fovea
 - Fixation
 - Smooth pursuit
- Keep the eyes still when the head moves
 - Vestibuloocular 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

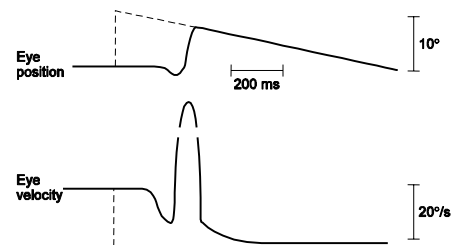
The vestibuloocular reflex.

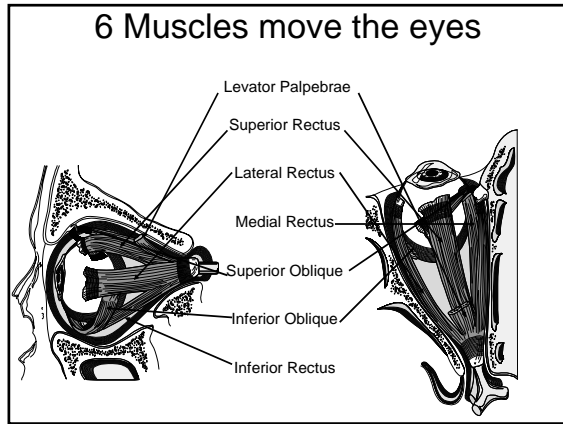
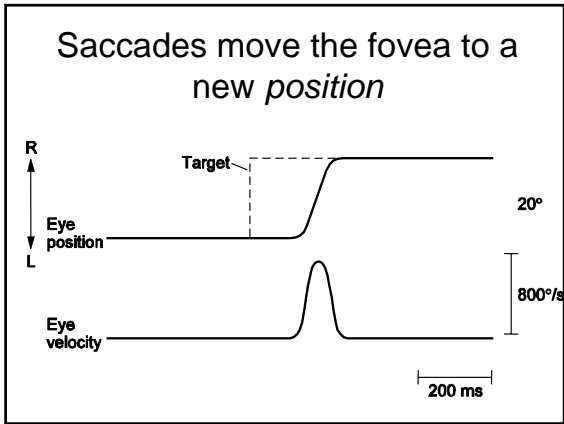
- The semicircular canals provide a head velocity signal.
- The vestibuloocular reflex (VOR) provides an equal and opposite eye velocity signal to keep the eyes still in space when the head moves.

The vestibular signal habituates, and is supplemented by vision – the optokinetic response



Smooth pursuit matches eye velocity to target velocity

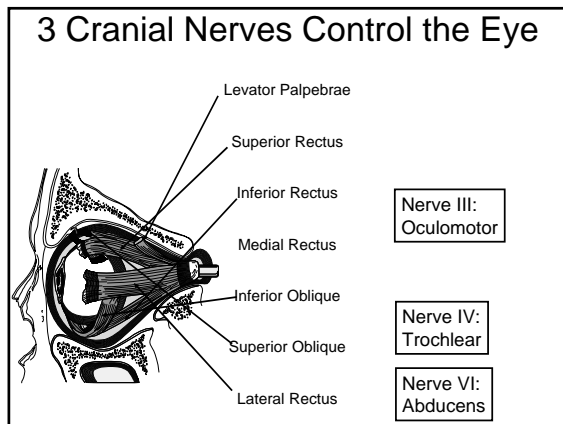




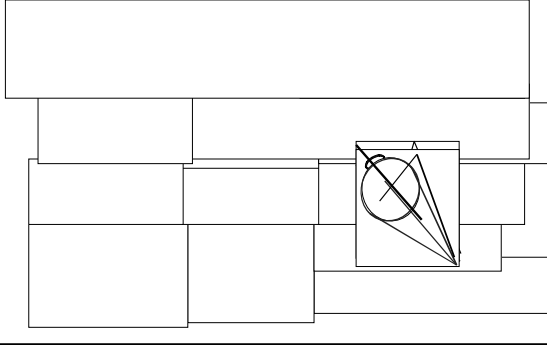
- ### How the single eye moves
- Horizontal:
 - Abduction (away from the nose)
 - Adduction (toward the nose).
 - Vertical:
 - Elevation (the pupil moves up)
 - Depression (the pupil moves down)
 - Torsional:
 - Intorsion: the top of the eye moves towards the nose
 - Extorsion: the top of the eye moves towards the ear.

- ### 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 extorts it.
 - Vertical recti tort the eye as well as elevate or depress it.
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- ### Oblique action depends on orbital position
- The superior oblique depresses the eye when it is adducted (looking at the nose).
 - The superior oblique intorts the eye when it is abducted (looking towards the ear)
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Left fourth nerve palsy



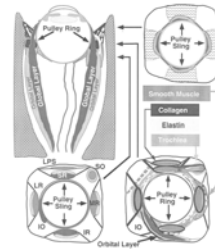
Listing's Law

- Torsion must be constrained or else vertical lines would not remain vertical.
- Listing's law accomplishes this: the axes of rotation of the eye from any position to any other position lie in a single plane, Listing's plane.
- This is accomplished by moving the axis of rotation half the angle of the eye movement

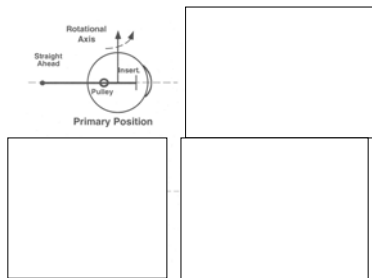
The pulleys: something new in orbital anatomy and physiology.

- How is Listing's law accomplished?
- Extraocular muscles have two layers
 - A global layer that inserts on the sclera
 - An orbital layer that inserts on a collagen-elastin structure between the orbit and globe. This structure serves as a PULLEY through which the global layer moves the eye.
- Moving the pulleys accomplish Listing's law. (Demer).

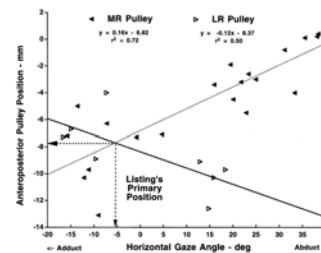
Pulley Anatomy

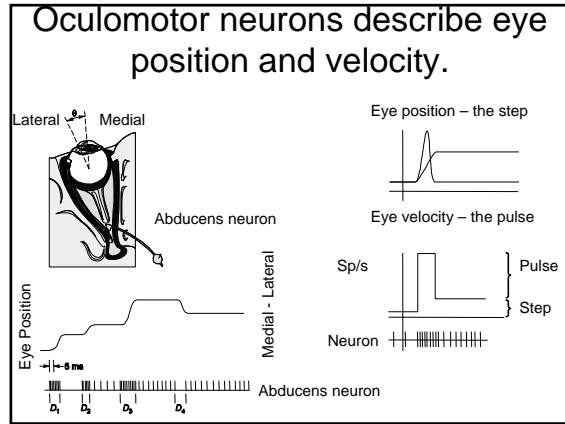
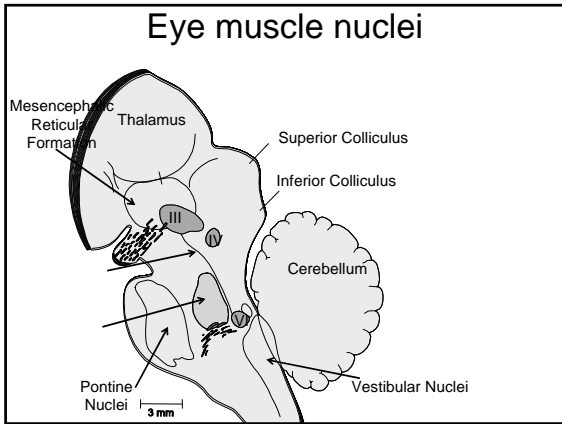


The pulleys



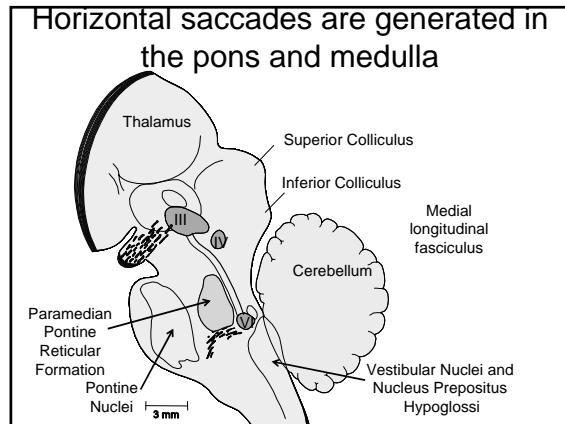
Horizontal rectus pulleys change their position with horizontal gaze.





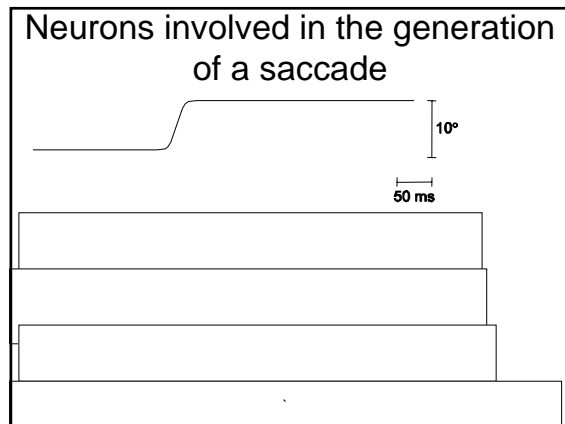
The transformation from muscle activation to gaze

- 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.



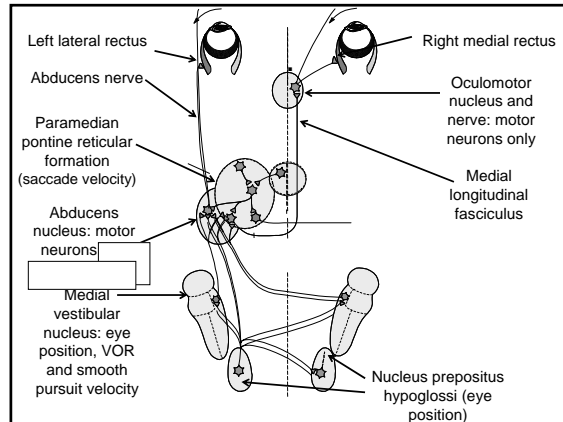
Digression on Neural Integration

- Intuitively, you move your eyes from position to position (the step).
- Higher centers describe a saccadic position error.
- The pontine reticular formation changes the position error to a desired velocity (the pulse).
- The vestibulo-ocular reflex also provides the desired velocity.
- In order to maintain eye position after the velocity signal has ended, this signal must be mathematically integrated.



Generating the horizontal gaze signal

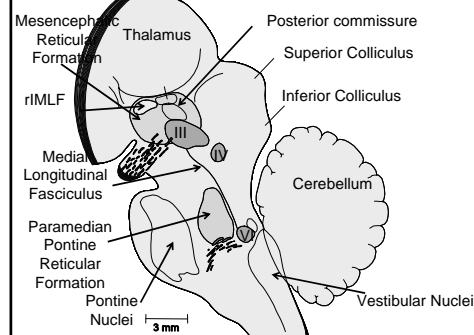
- The medial rectus of one eye and the lateral rectus of the other eye must be coordinated.
- This coordination arises from interneurons in the abducens nucleus that project to the contralateral medial rectus nucleus via the medial longitudinal fasciculus.



To reiterate

- Ocular motor neurons describe eye position and velocity.
- For smooth pursuit and the VOR the major signal is the velocity signal, which comes from the *contralateral* medial vestibular nucleus.
- The neural integrator in the medial vestibular nucleus and nucleus prepositus hypoglossi converts the velocity signal into a position signal which holds eye position.
- For horizontal saccades the paramedian pontine reticular formation converts the position signal from supranuclear centers into a velocity signal.
- This signal is also integrated by the medial vestibular nucleus and the nucleus prepositus hypoglossi.
- Abducens interneurons send the position and velocity signals to the oculomotor nucleus via the medial longitudinal fasciculus.

Vertical movements and vergence are organized in the midbrain



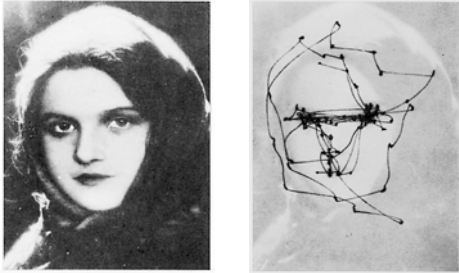
Internuclear ophthalmoplegia

- 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 version signal cannot reach the medial rectus nucleus, but the convergence signal can.

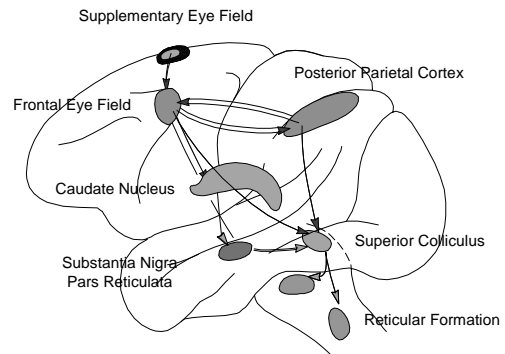
Supranuclear control of saccades

- 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, and make slightly hypometric saccades with longer reaction times. Often their saccades are normal: if they can see it they can make saccades to it.
- Humans with frontal lesions cannot make antisaccades.

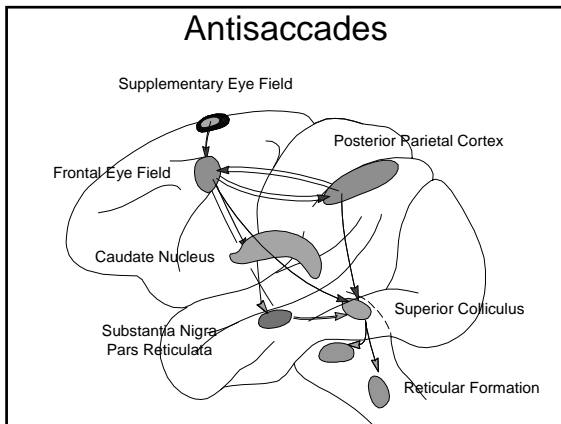
The Antisaccade Task



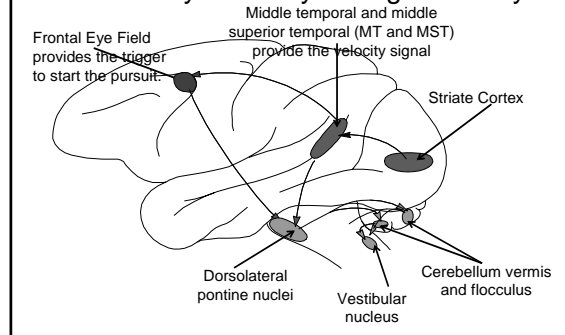
The Antisaccade Task

- 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



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



Smooth pursuit

- Requires cortical areas that compute target velocity, the dorsolateral pontine nuclei, 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