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
Muscles move the eyes

- Superior Rectus
- Medial Rectus
- Superior Oblique
- Inferior Oblique
- Inferior Rectus
- Lateral Rectus
- Levator Palpebrae

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.
Cranial Nerves Control the Eye

Nerve III: Oculomotor
Nerve IV: Trochlear
Nerve VI: Abducens

Hyperopia in central gaze.
Worse on right gaze.
Better on left gaze.
Worse looking down to right.
Better looking up to right.
Head tilt to right improves gaze.
Head tilt to left worsens gaze.

Left fourth nerve palsy

Eye muscle nuclei

Mesencephalic Reticular Formation
Thalamus
Superior Colliculus
Inferior Colliculus
Cerebellum
Pontine Nuclei
Vestibular Nuclei
Oculomotor neurons describe eye position and velocity.

Eye position – the step

Eye velocity – the pulse

\[ F(t) = r\theta + k(d\theta/dt) \]

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 ocular motor 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

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Supranuclear control of saccades

- Supplementary Eye Field
- Frontal Eye Field
- Caudate Nucleus
- Substantia Nigra
- Superior Colliculus
- Reticular Formation
- Posterior Parietal Cortex
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

Supplementary Eye Field

Frontal Eye Field

Posterior Parietal Cortex

Caudate Nucleus

Substantia Nigra - Pars Reticulata

Superior Colliculus

Reticular Formation

Smooth pursuit matches eye velocity to target velocity

Eye position

200 ms

10°

Eye velocity

20°/s

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

Middle temporal and middle superior temporal (MT and MST)
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.