Extraocular Muscles and Ocular Motor Control of Eye Movements

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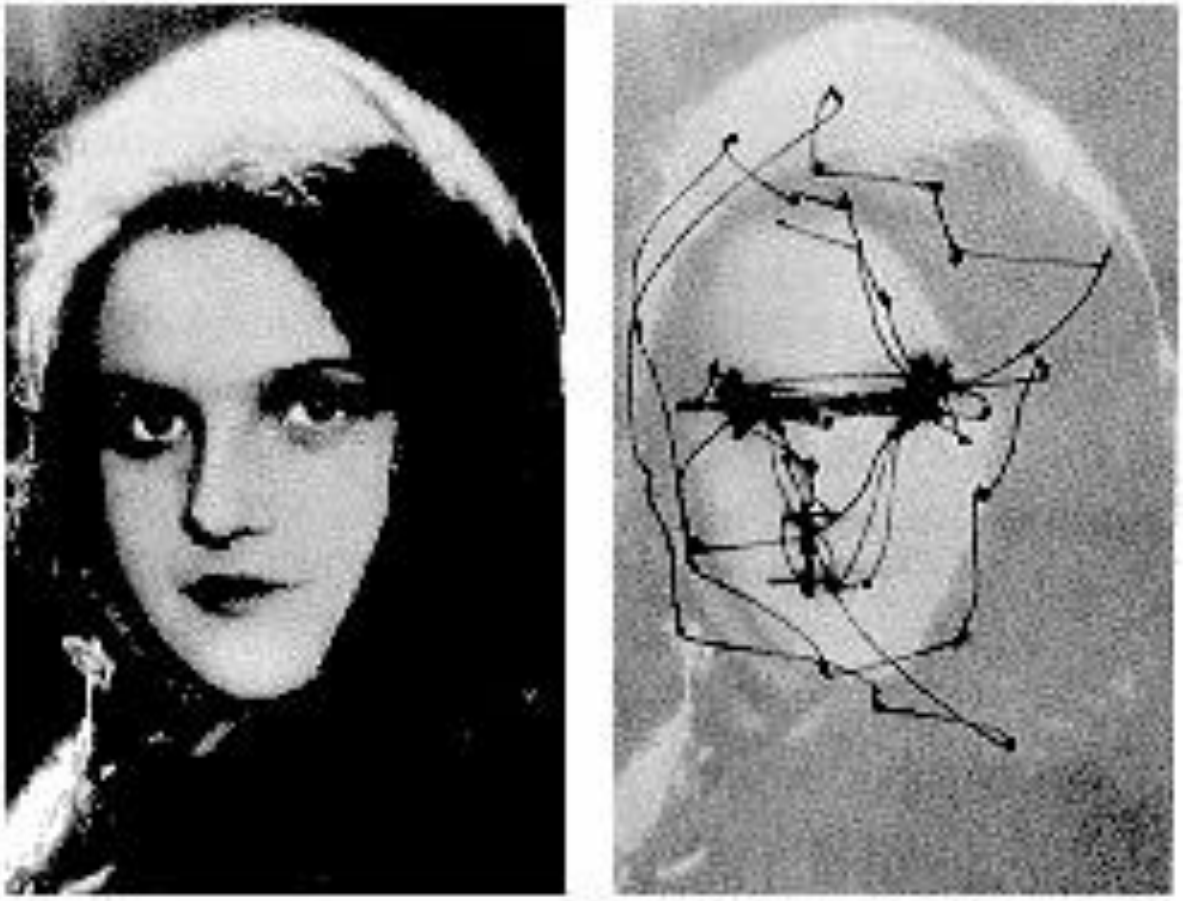
Your Eyes Are Constantly Moving.



Yarbus, 1967

Eye Movements and Mental Activity

relationship first
demonstrated
by Yarbus (1967)

Original image

Free view

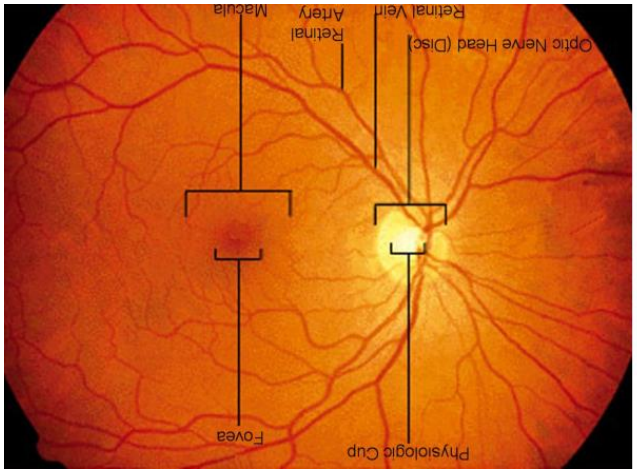
Estimate the ages of the people

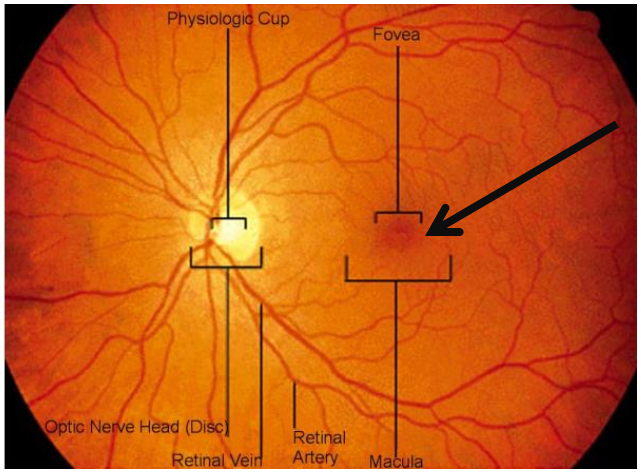
Remember the positions of the people

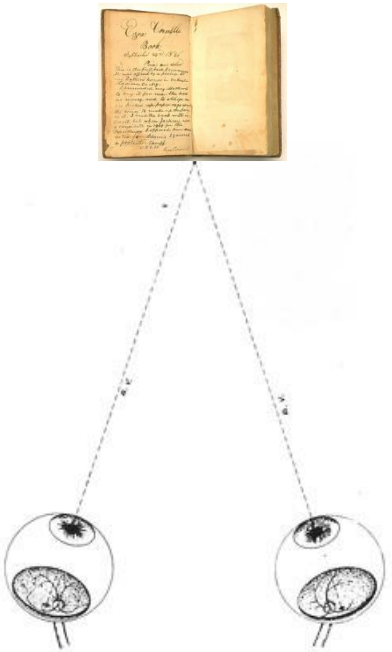
Surmise what the family was doing

What is the goal of eye movements?

To maintain alignment of the two foveae on objects of interest in the visual field.







The fovea is less than 1 mm in diameter and consists almost entirely of cones.

This is the area with the “best” or sharpest vision.

What happens if the eyes are not aligned?

Misalignment of the eyes results in failure of a point of visual interest to fall on the same region of each retina.

Adults: diplopia or “double vision”

Children: if untreated they can develop permanent reduction in visual acuity unilaterally (in one eye).

Significant differences exist in the control of different types of eye movements.

Try this:

1. Stare at your finger while you shake your head back and forth.
2. Hold your head steady and shake your finger back and forth.

What is the main difference here?

Six Fundamental Tasks of the Ocular Motor System

1. Fixation: Maintenance of focus on a particular spot in the visual world. In other words, your eyes need to stay still.
2. Saccades: Rapid conjugate shifts in gaze attention.
3. Smooth pursuit: Continued fixation on slowly moving objects when the head is stationary.
4. Vestibulo-ocular reflex (VOR): Fixation on a stationary object during brief head movements.
5. Optokinetic nystagmus (OKN): Fixation on stationary images during sustained head rotations or continued small eye movements to moving images in the visual field.
6. Vergence system : For viewing close stationary objects - head is stationary. Eyes both turn toward the midline.

Conjugate and Non-Conjugate Eye Movements

Unlike the vast majority of other movements, the eyes always move in a coordinated manner.

- Conjugate movements: eyes move in the same direction at the same time.
  - Saccades
  - Smooth pursuit
  - Optokinetic movements
  - Vestibulo-ocular reflex

Conjugate and Non-Conjugate Eye Movements

- Disconjugate movements: eyes do NOT move in the same direction at the same time, but still move the same amount in a coordinated manner – just in the opposite direction from each other.
  - Vergence movements (near vision)

Six Fundamental Tasks of the Ocular Motor System

Fixation: Maintenance of focus on a particular spot in the visual world. In other words, the eyes need to stay "motionless" for a brief moment in order for you to see mountains in the distance, for example, or a letter on a page of text.

We call this the primary position of gaze.

Six Fundamental Tasks of the Ocular Motor System

Saccades: Rapid conjugate shifts in gaze attention.

These are the fastest movements human muscles can make, up to 660-900 degrees/sec.

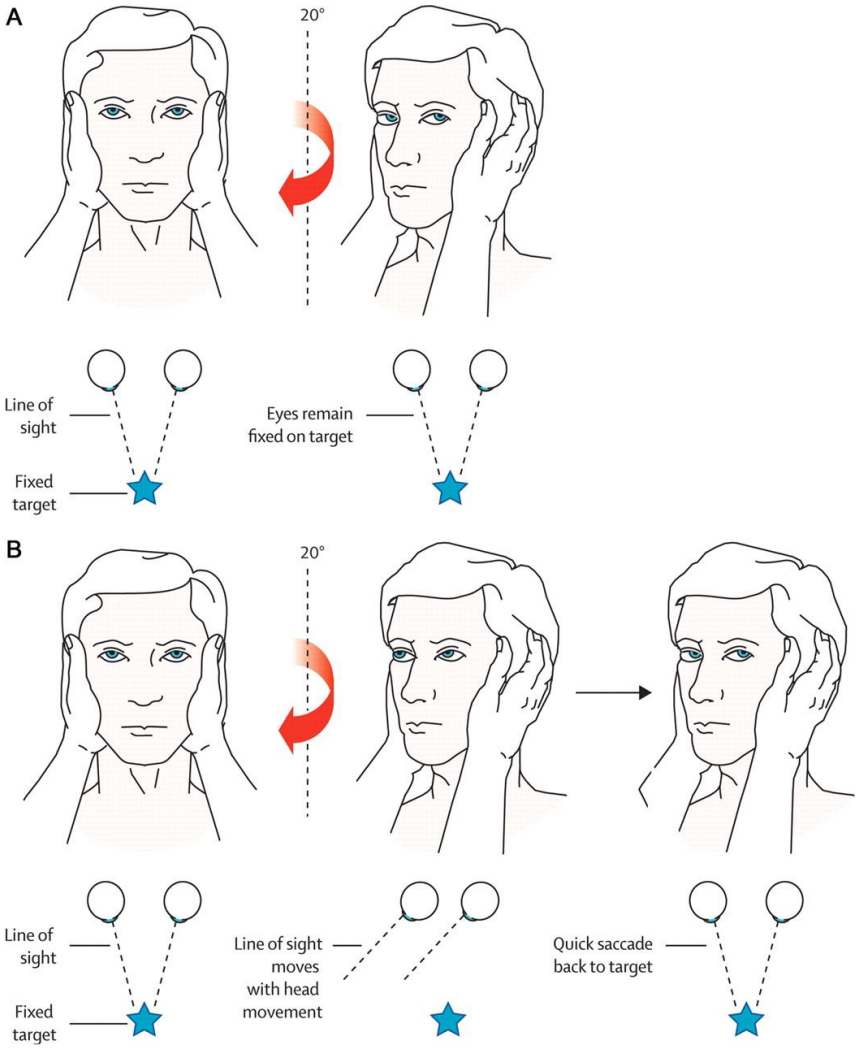
Leigh and Zee, 2006

Six Fundamental Tasks of the Ocular Motor System

Smooth pursuit: Fixation on slowly moving objects when head is stationary.

Leigh and Zee, 2006

Vestibulo-ocular reflex (VOR): Fixation on stationary objects during brief head movements.



AMERICAN ACADEMY OF NEUROLOGY

Six Fundamental Tasks of the Ocular Motor System

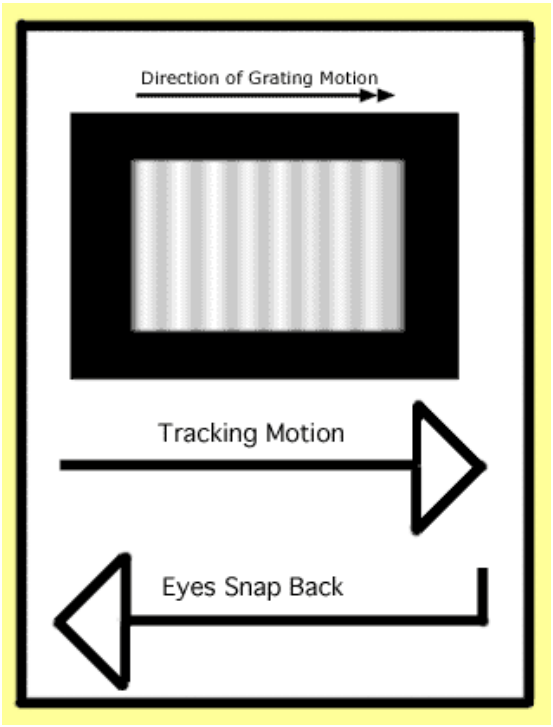
Vestibulo-ocular reflex (VOR): Fixation on stationary objects during brief head movements.

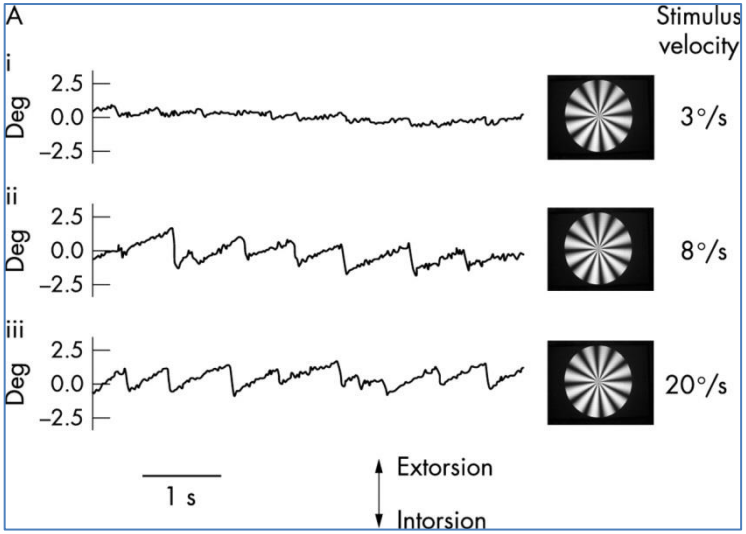
Keeps the visual world stable on the foveae.

Leigh and Zee, 2006

Optokinetic nystagmus (OKN)

Allows you to fixate your vision on stationary images during sustained head rotations. This also allows you to track moving images close to you.



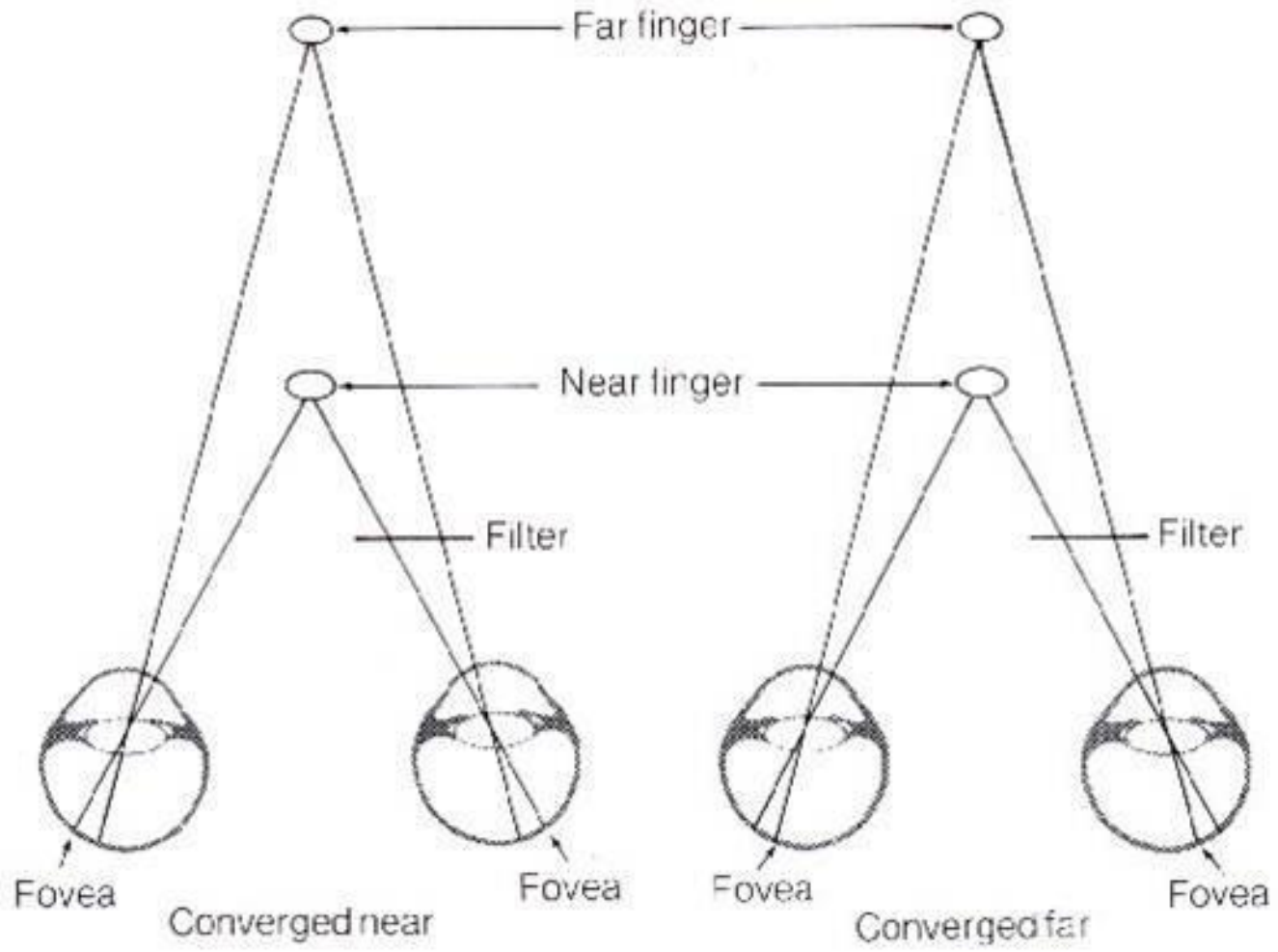


Six Fundamental Tasks of the Ocular Motor System

Optokinetic nystagmus (OKN): Allows you to fixate your vision on stationary images during sustained head rotations or track nearby moving images with head fixed.

Leigh and Zee, 2006

Vergence: Fixation on near points in the visual world



Six Fundamental Tasks of the Ocular Motor System

Vergence system: To view stationary objects that are close to you with your head stationary.

Leigh and Zee, 2006

Six Fundamental Tasks of the Ocular Motor System

What is the goal of all these systems?

Six Fundamental Tasks of the Ocular Motor System

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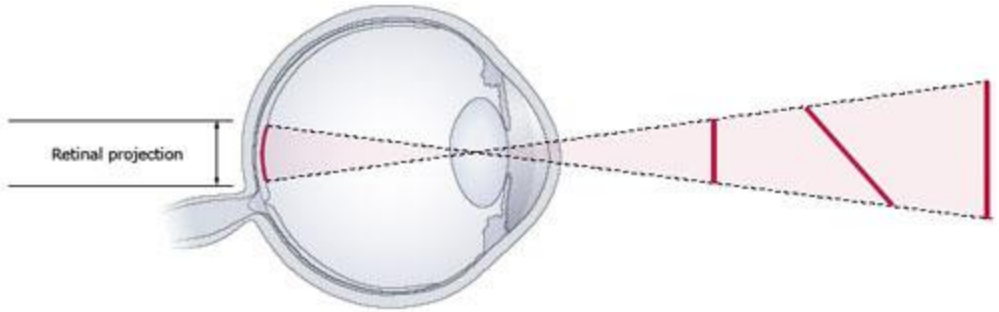
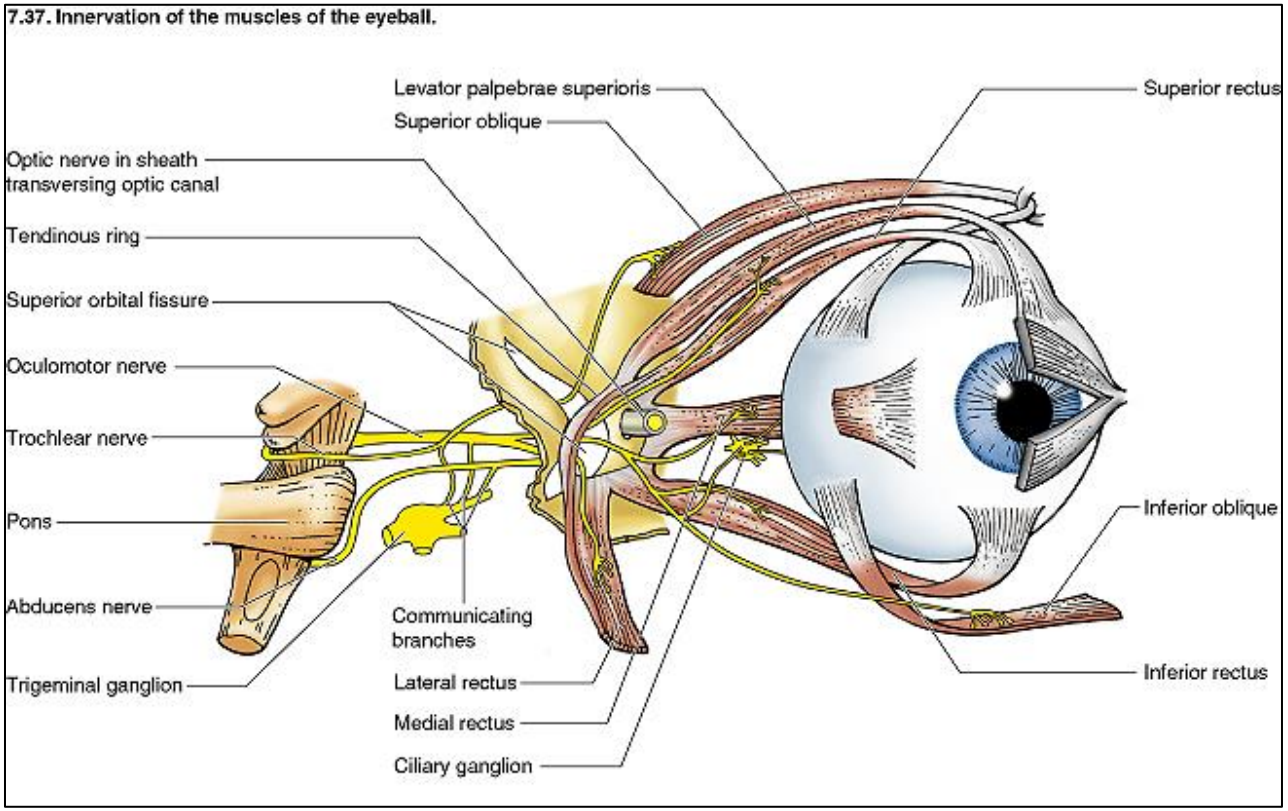


To ensure a stable image of the same part of the visual world on the same parts of each retina.

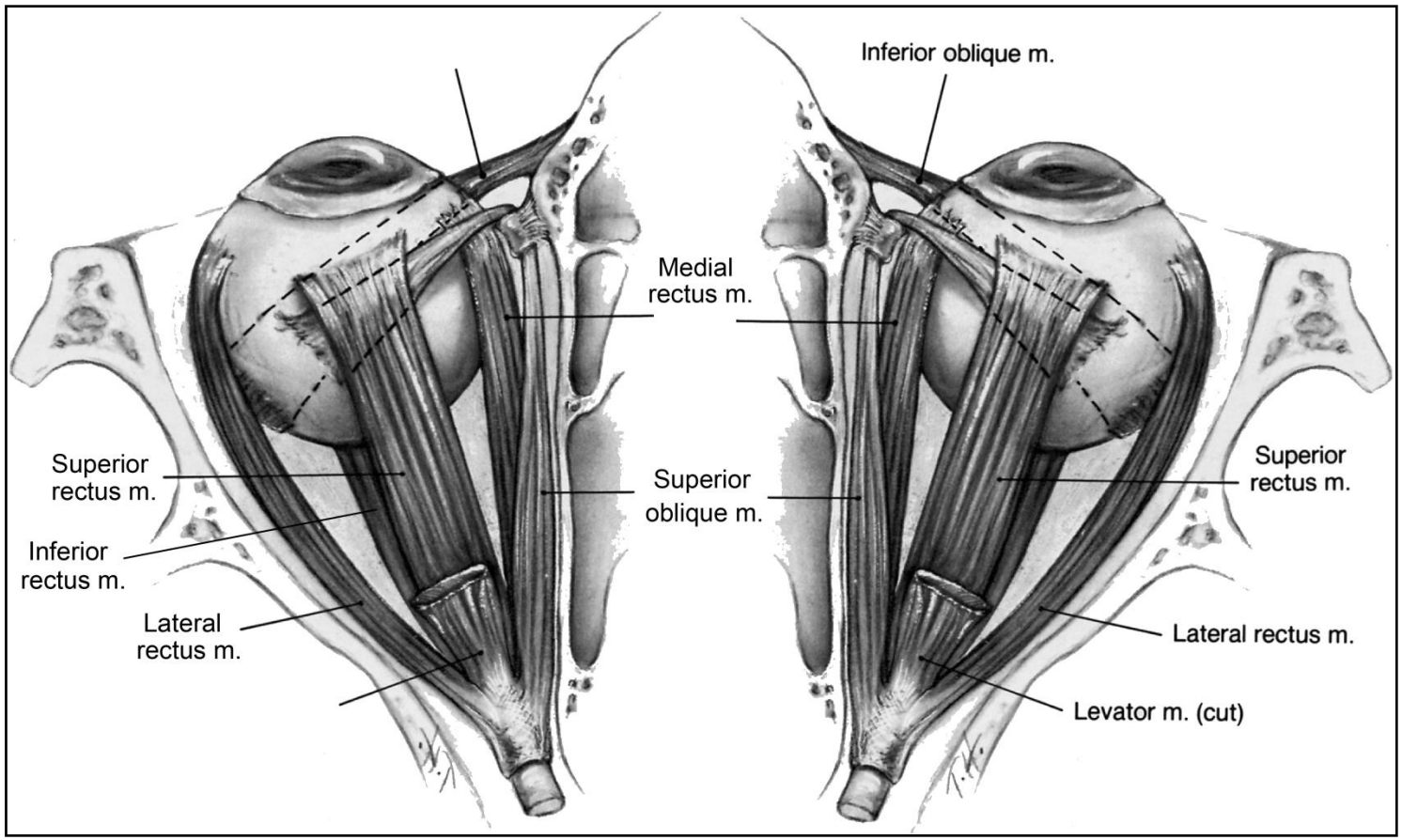
Components of the Ocular Motor System

How does the brain move the eyes?



- Extraocular muscles: 6 per orbit
- Innervated by 3 different cranial motor nerves: oculomotor (CNIII), trochlear (CNIV), and abducens (CNVI)

Extraocular Muscles

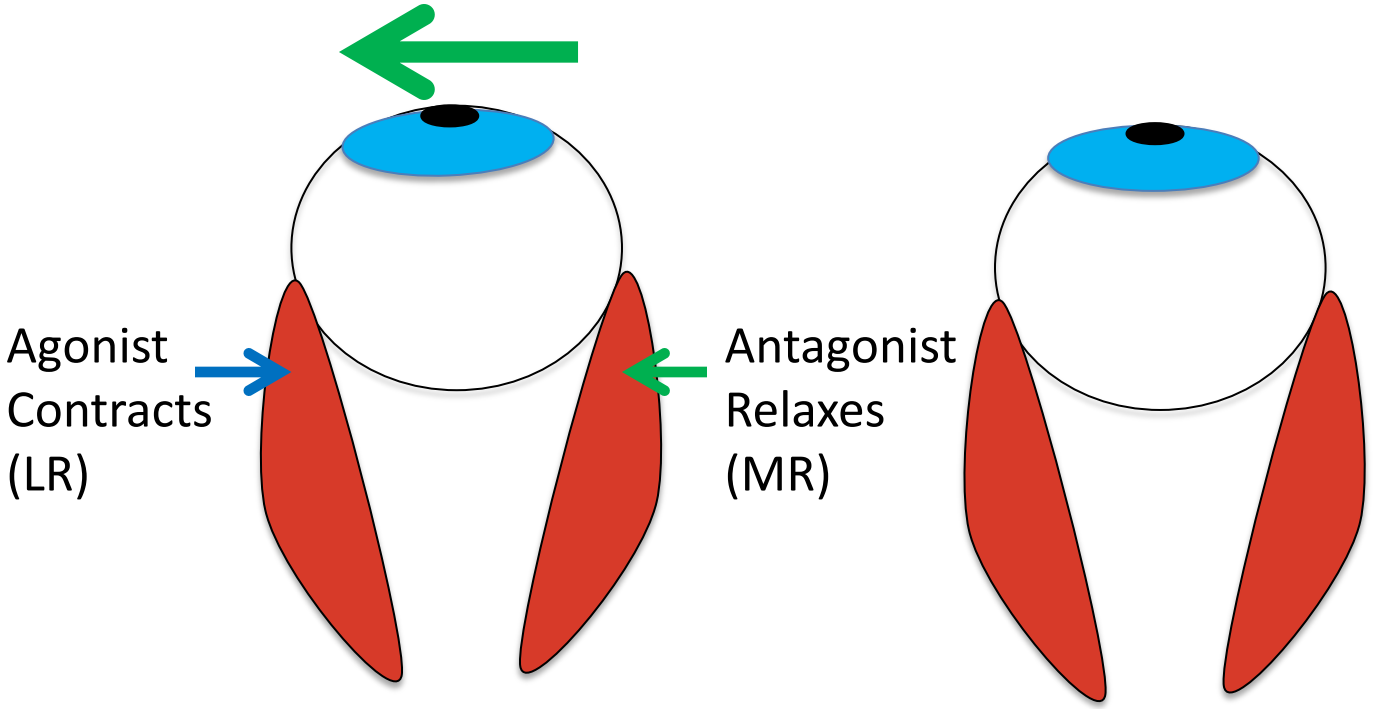


In each orbit:

4 rectus muscles: superior, medial, inferior, lateral

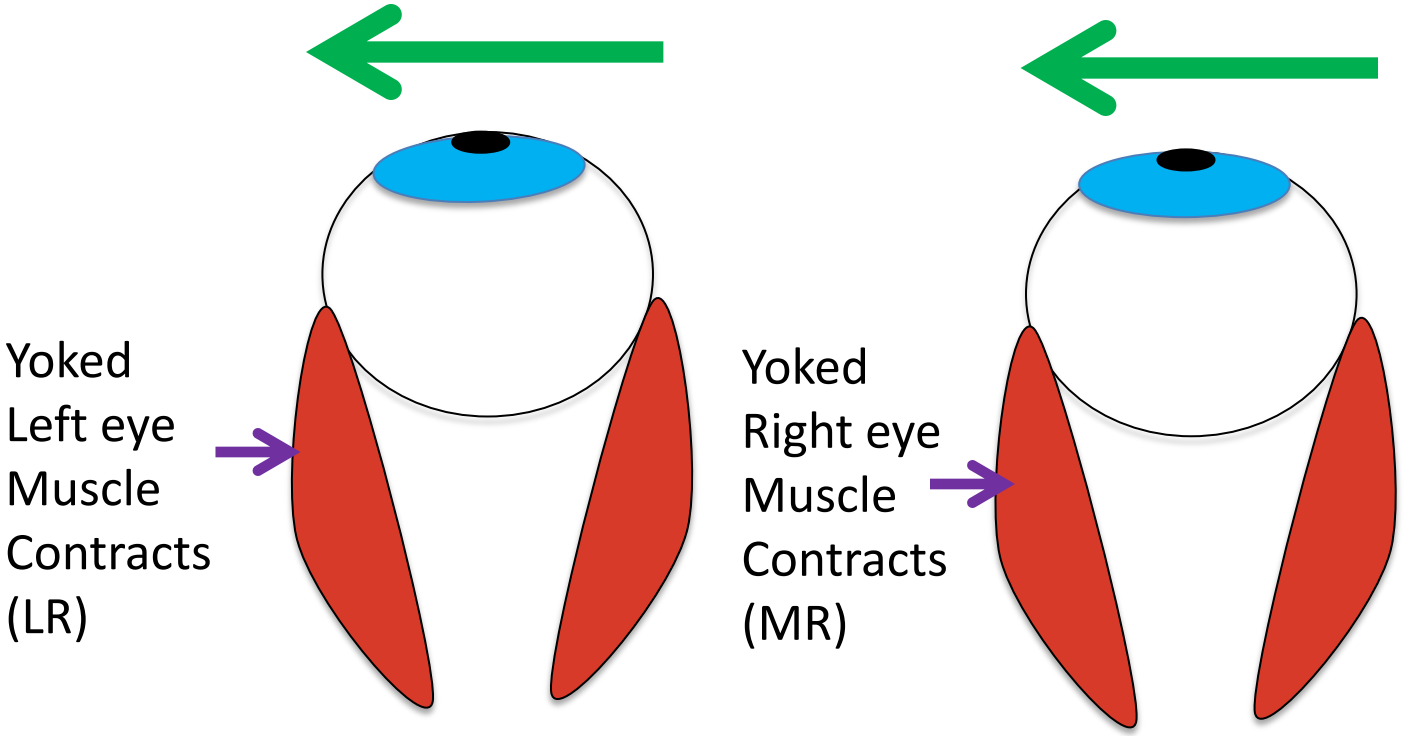
2 oblique muscles: superior, inferior

Some Definitions:
Agonist/Antagonist Muscle Pairs



The lateral and medial rectus muscles attached on each side of one globe form an agonist/antagonist pair. When one contracts, the other relaxes.

Some Definitions: Yoked Muscles



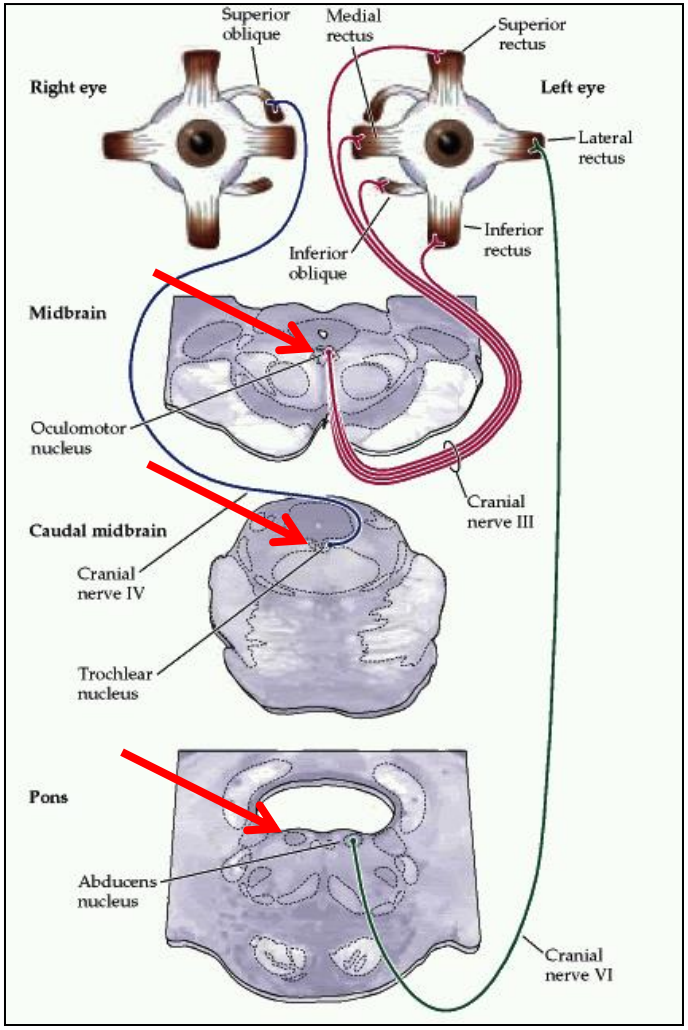
Each pair of medial and lateral rectus muscles, attached to the same side as the direction of movement in each orbit forms a yoked muscle pair. Both contract in unison.

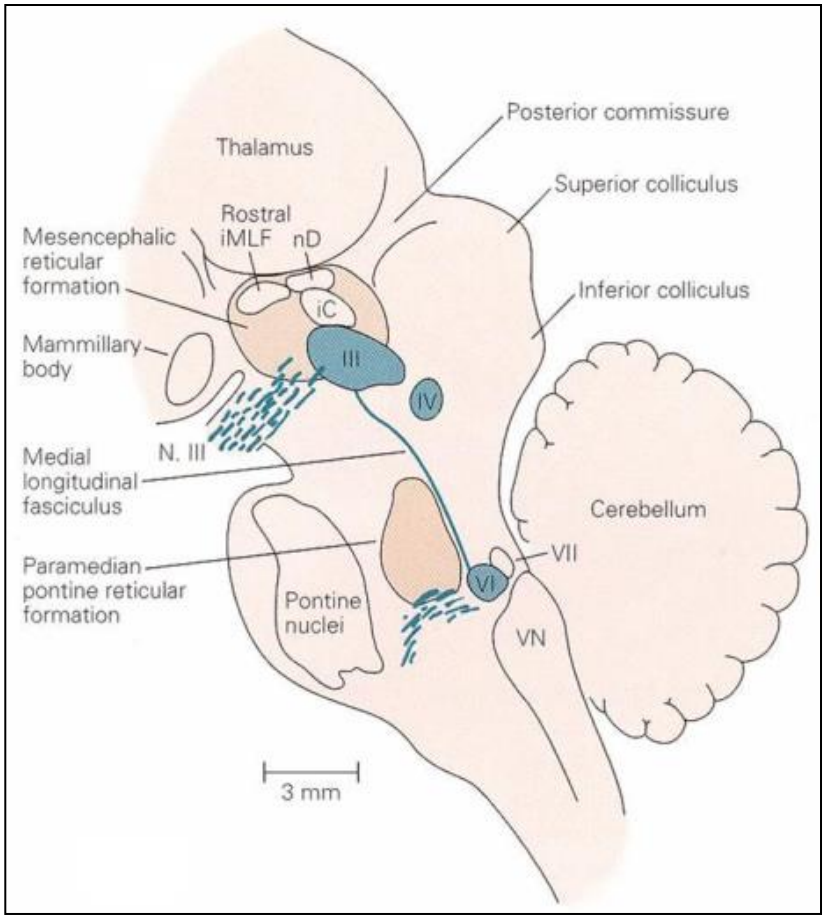
The EOM are controlled by 3 ocular motor nuclei in the brainstem: oculomotor (CNIII), trochlear (CNIV), and abducens (CNVI)

Oculomotor CNIII

Trochlear CNIV

Abducens CNVI





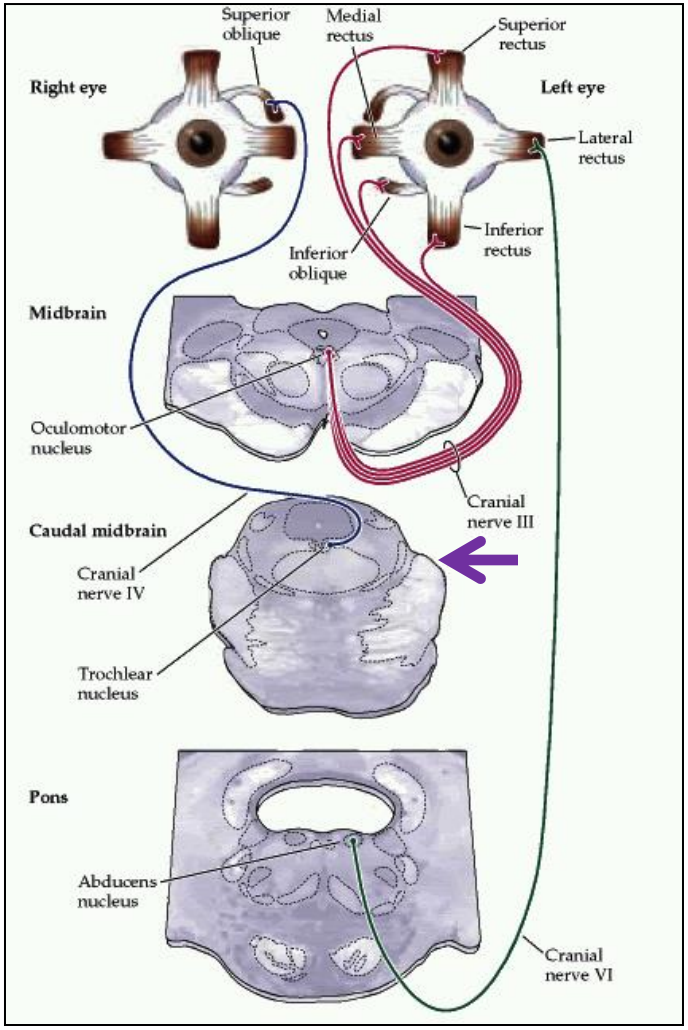
These motor neurons control both eye <u>position</u> and <u>velocity</u> of eye movements.

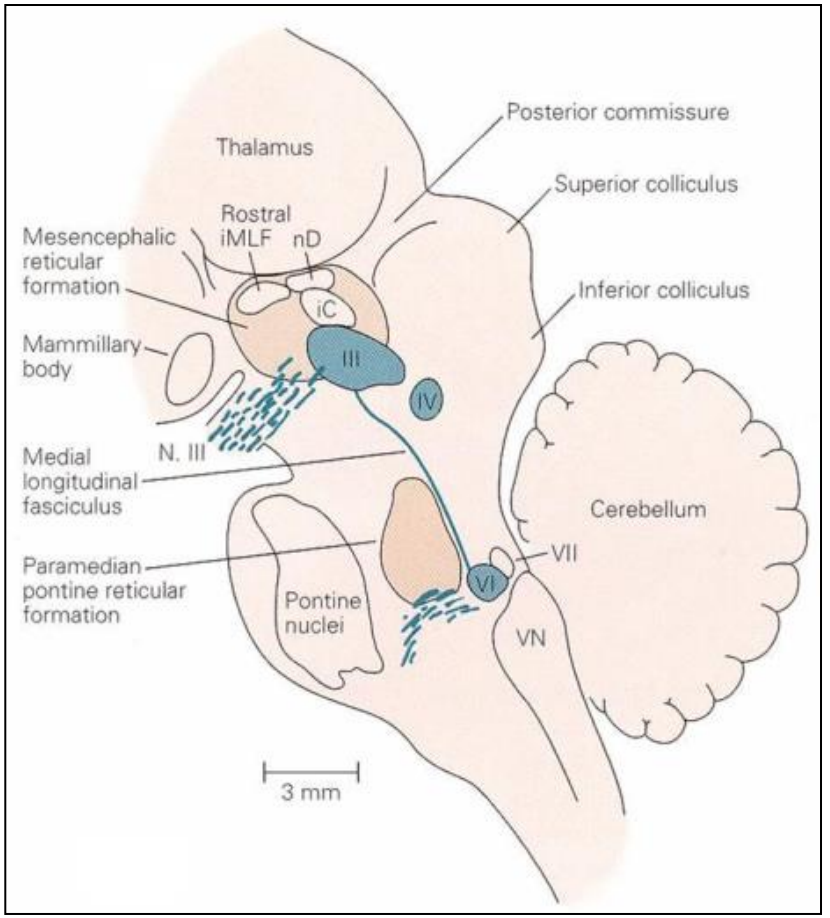
The EOM are controlled by 3 ocular motor nuclei in the brainstem: oculomotor, trochlear and abducens

Oculomotor CNIII

Trochlear CNIV

Abducens CNVI





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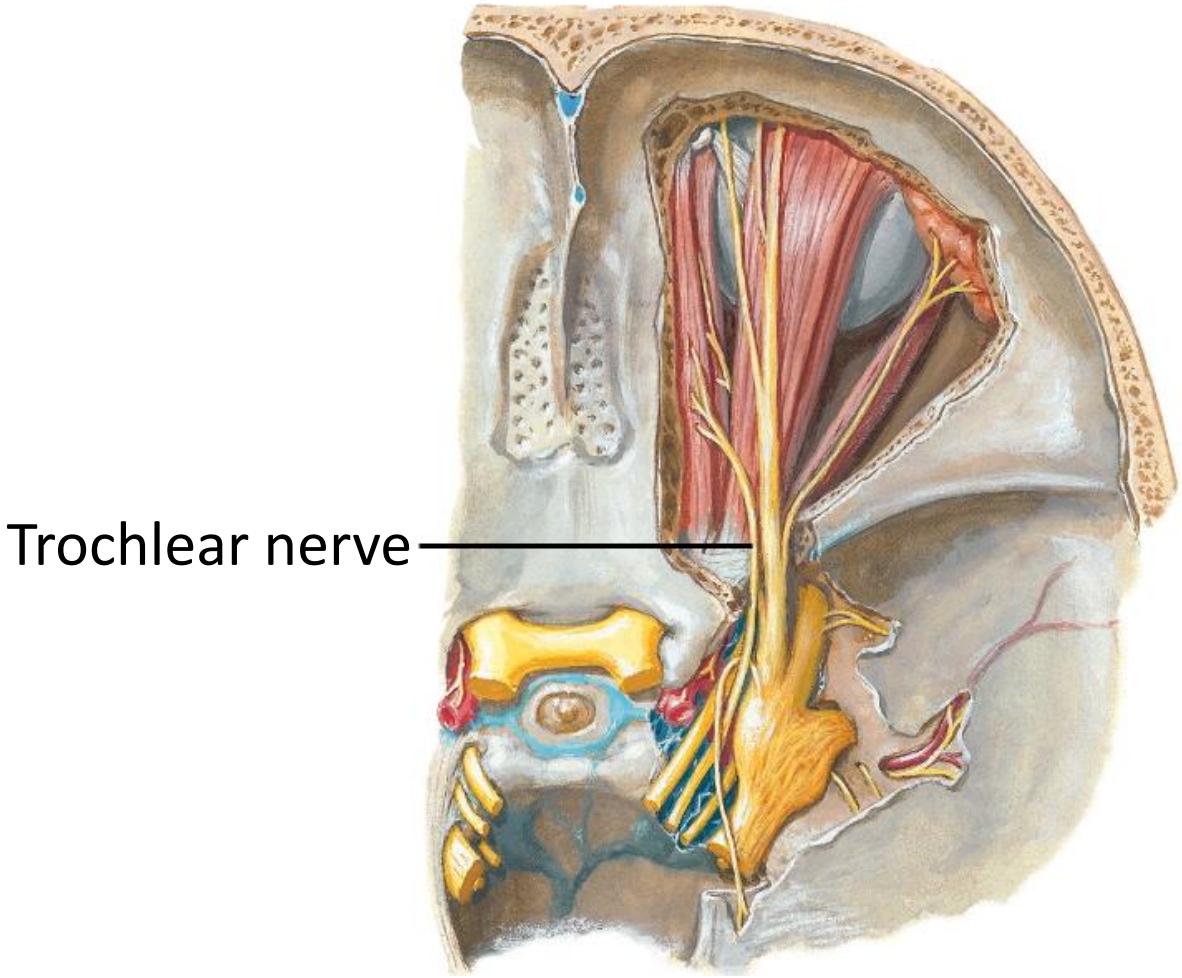
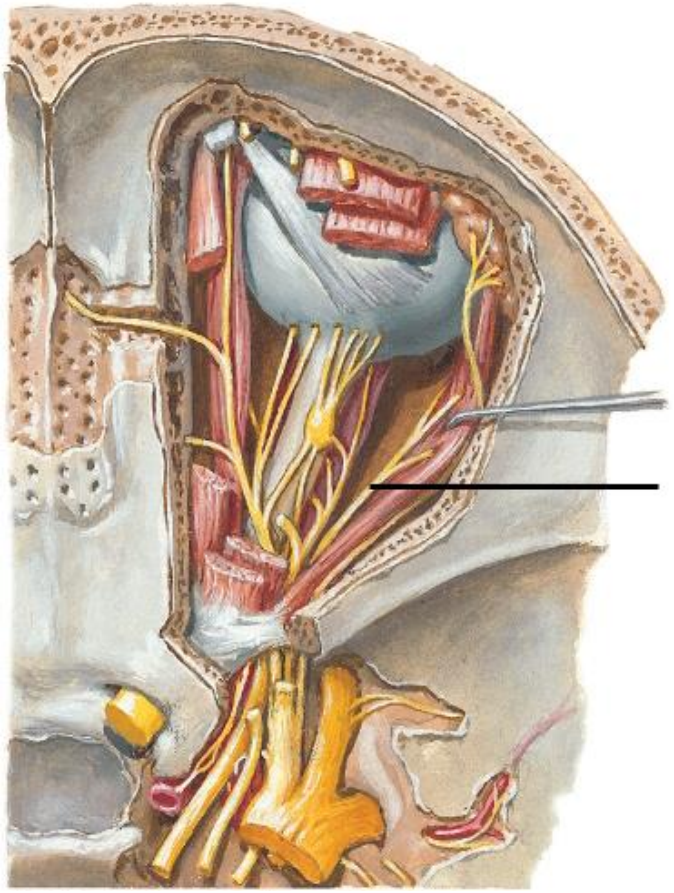
Innervation of the Extraocular Muscles



The trochlear nerve (cranial nerve 4 - CNIV) innervates the superior oblique muscle.

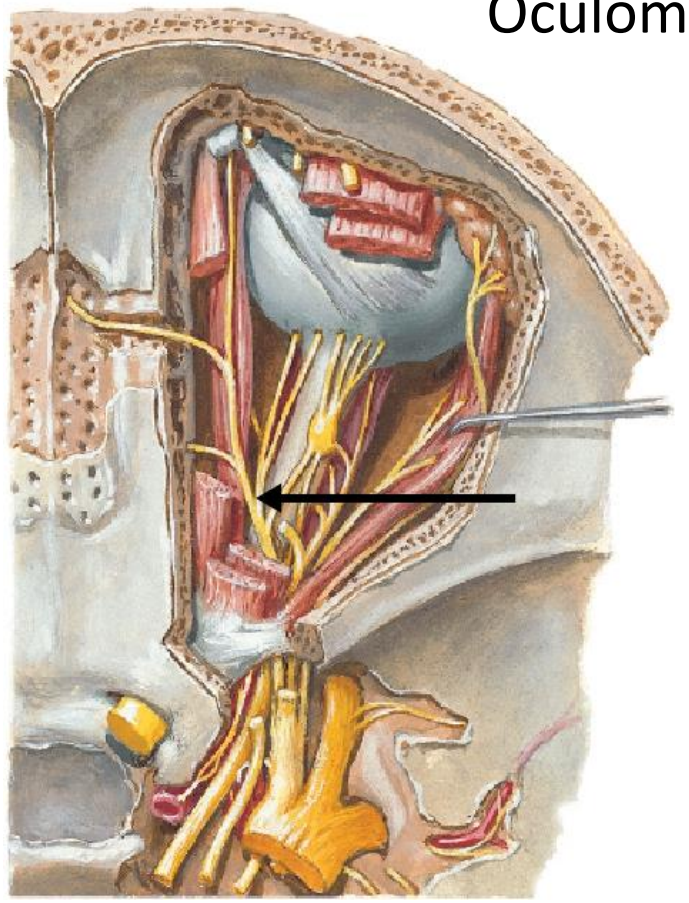
Innervation of the Extraocular Muscles

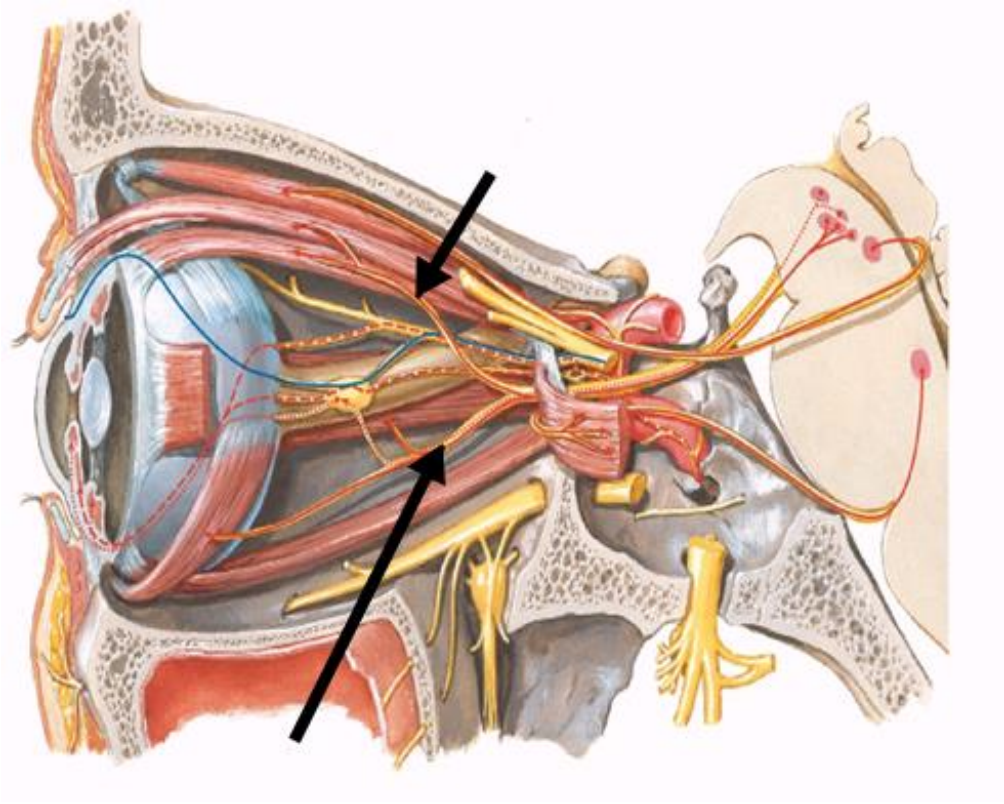


The abducens nerve (cranial nerve 6 - CNVI) innervates the lateral rectus muscle.

Innervation of the Extraocular Muscles

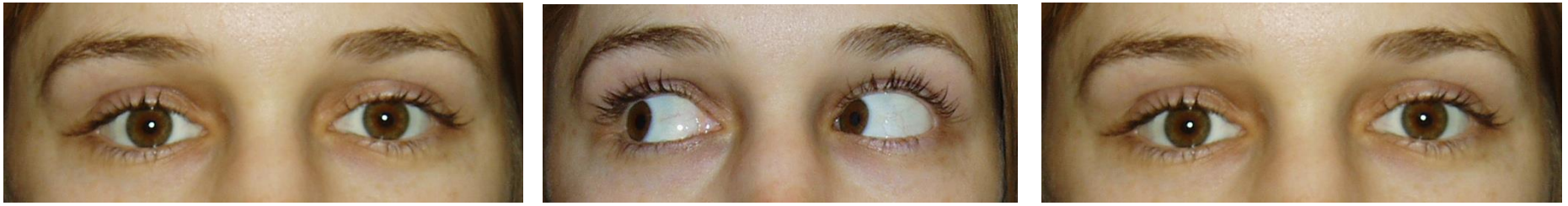
Oculomotor nerve





The oculomotor nerve (cranial nerve 3 – CNIII) innervates the other four muscles: superior rectus, medial rectus, inferior rectus and inferior oblique – plus the levator palpebrae superioris.

Saccades



Saccades are fast, yoked eye movements that move the eye quickly from fixation to a new position of gaze.

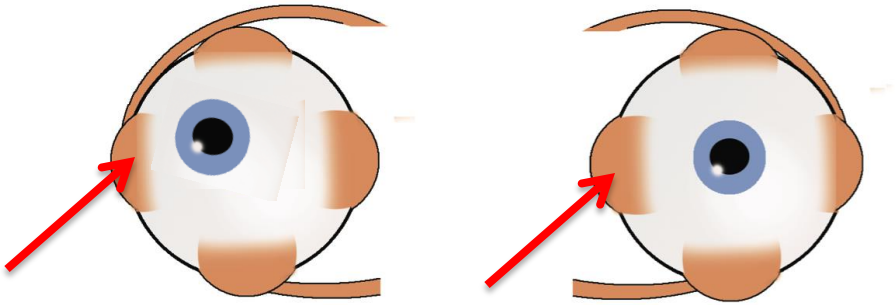
Used for:

- Quick reset phase of VOR and OKN (head moves, eyes move in opposite direction)
- Gaze shift in response to a novel stimulus in the visual field
- Gaze shift during reading
- Searching novel scenes
- Return gaze to remembered locations

Leigh and Kennard Brain 2004

Horizontal Eye Movements

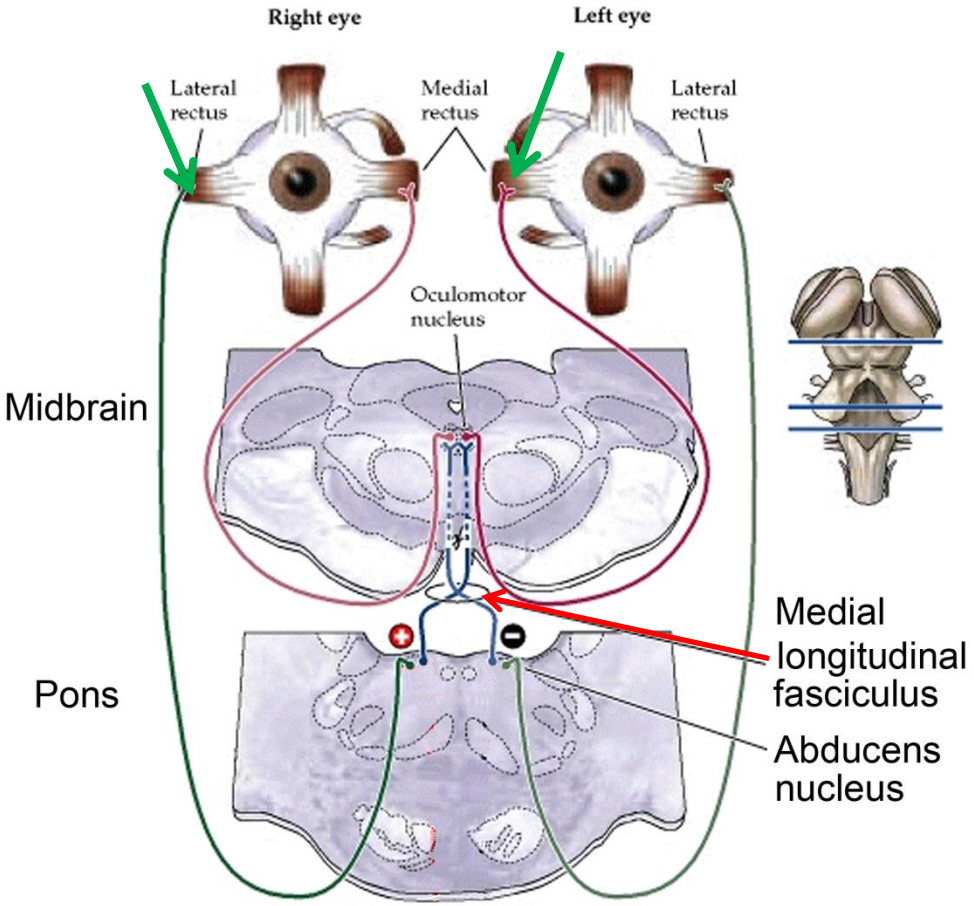
Looking to the right



Right lateral rectus

Left medial rectus

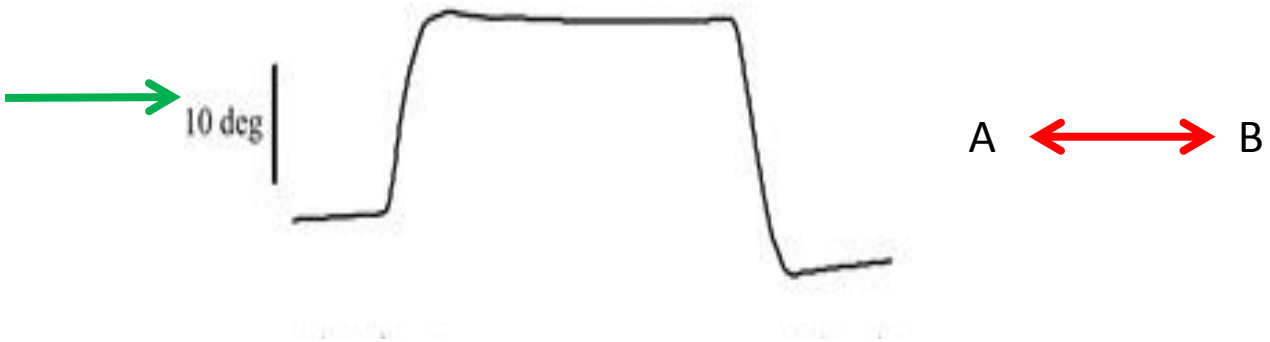
Looking to the Right



Contraction of the <u>lateral rectus</u> of the right eye and the <u>medial rectus</u> of the left eye by excitation from neurons in the abducens and oculomotor nuclei

Saccades: How Neurons Move your Eyes to Fixate on a New Object

<u>Eye position</u>: Eyes look to the right - "On direction"



Sylvestre P A , Cullen K E J Neurophysiol 1999

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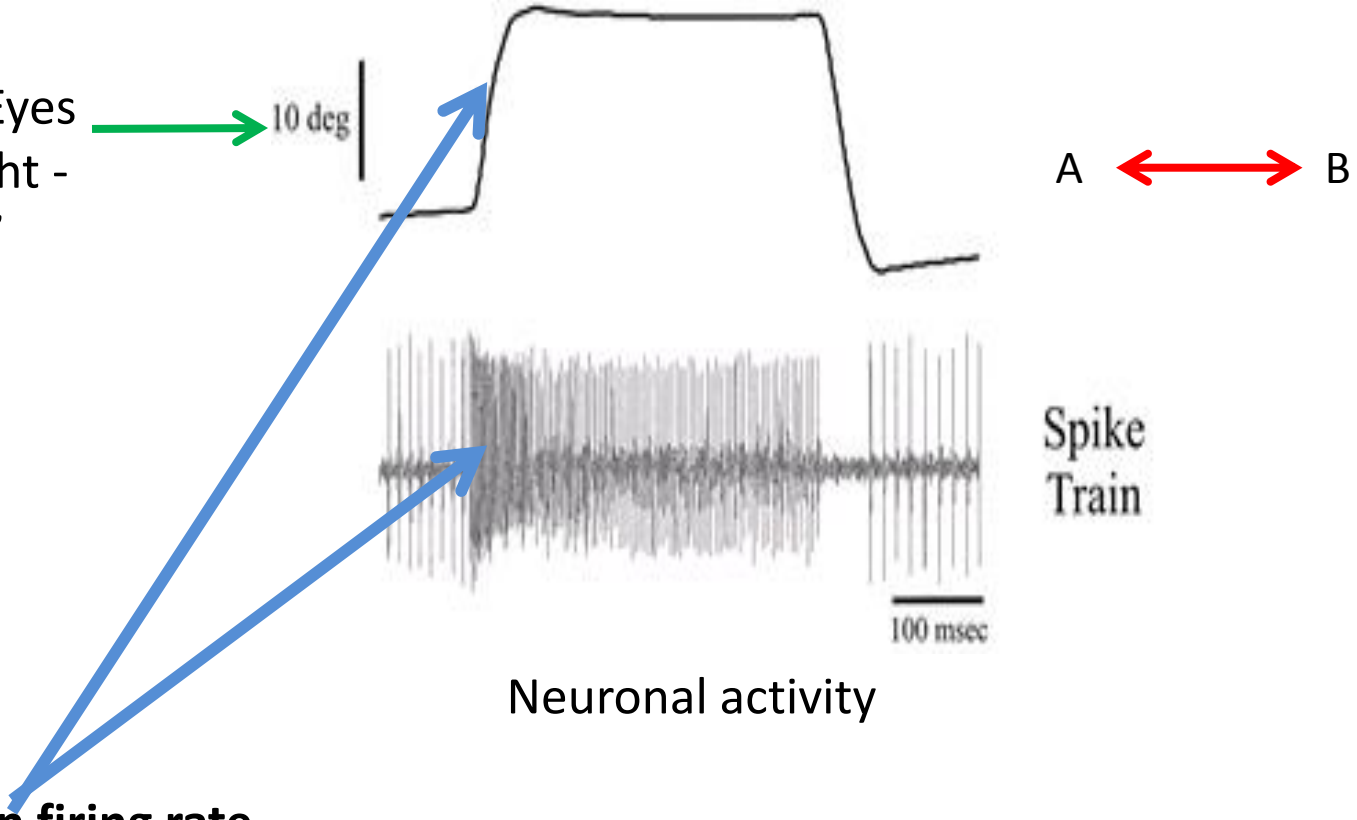

Neuronal activity

Pulse: burst in firing rate
Determines velocity and eye position

Activity of an example abducens neuron during an ipsilaterally and a contralaterally directed saccade.

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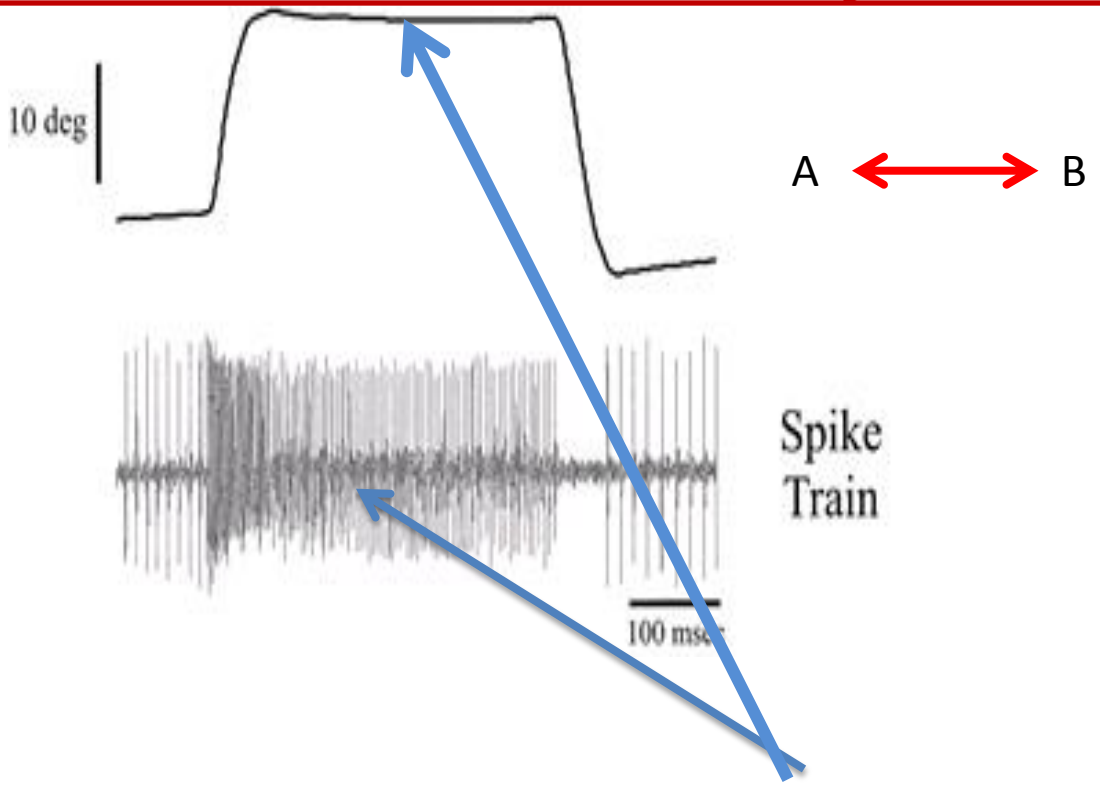

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Step: tonic firing
Determines fixation period

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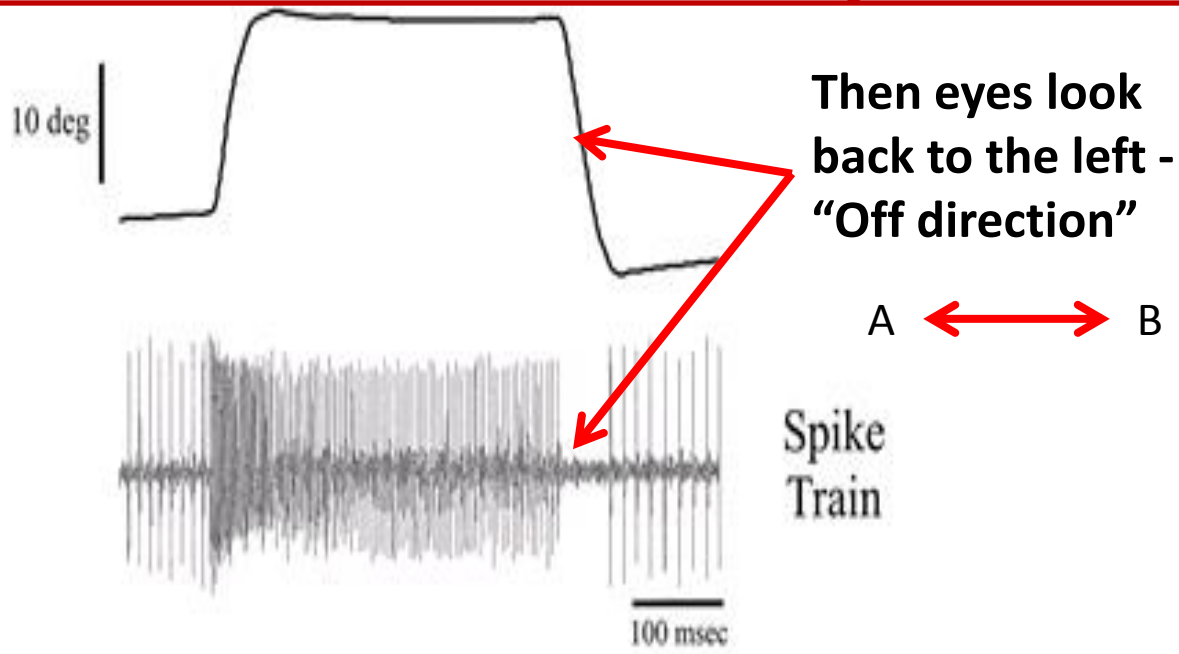

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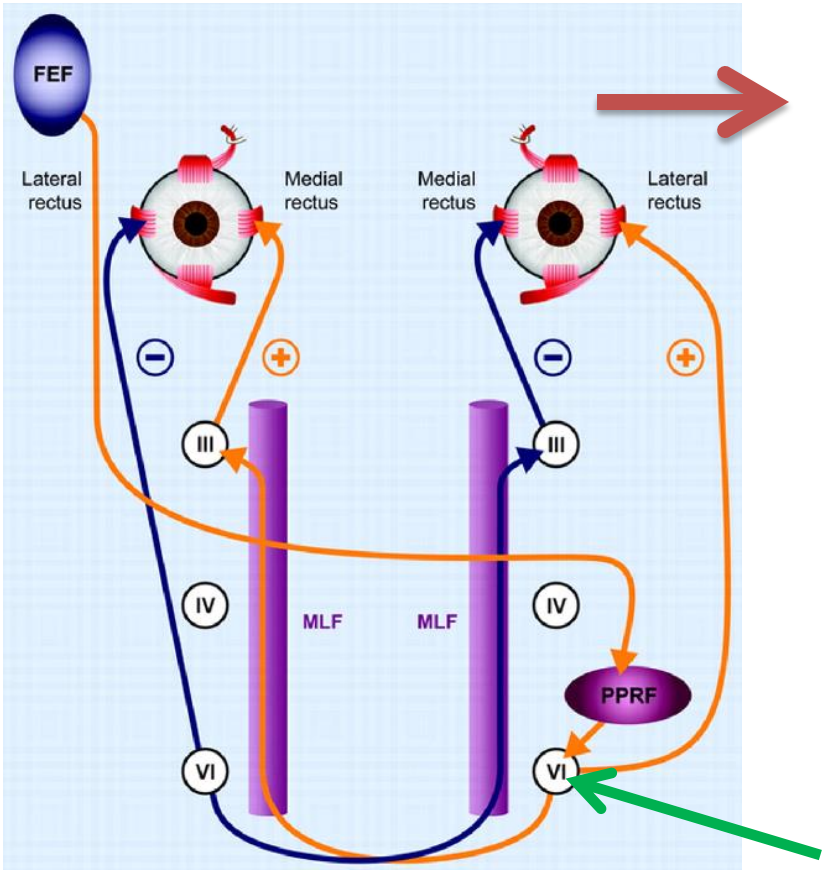
The Ocular Motor Nuclei Coordinate the Contraction of Yoked Extraocular Muscles and the Inhibition of Antagonist Extraocular Muscles



Voluntary Horizontal eye movements in the direction of the brown arrow (left): LLR and RMR are activated and LMR and RLR are inhibited.

FEF: frontal eye fields, MLF: medial longitudinal fasciculus, PPRF: paramedian pontine reticular formation

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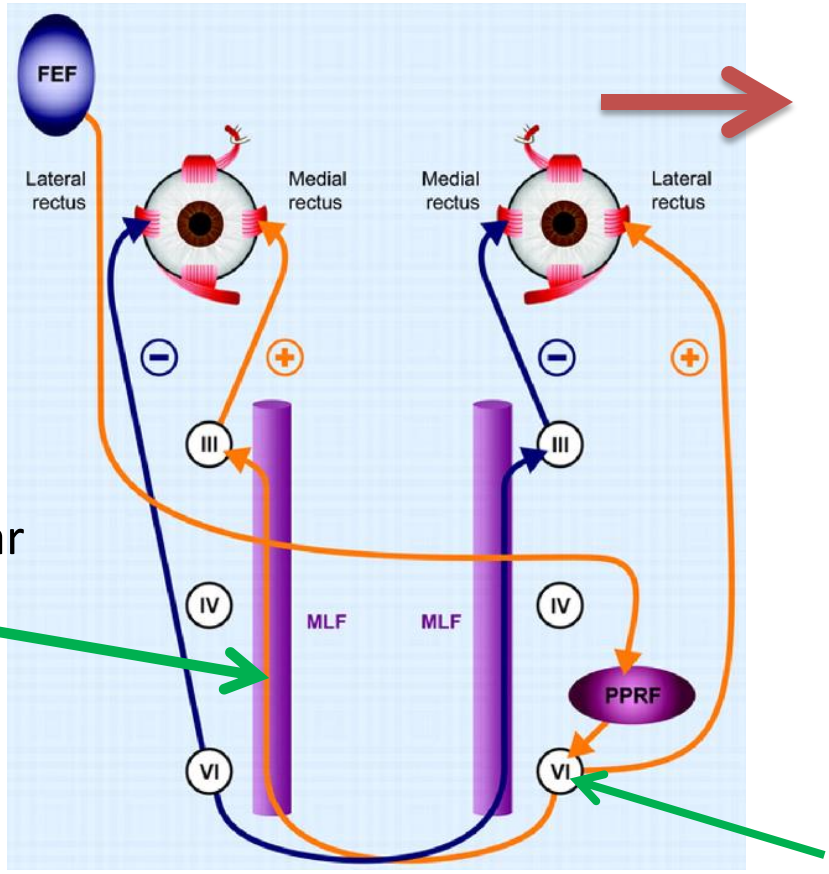

Excitation via internuclear neurons in the medial longitudinal fasciculus

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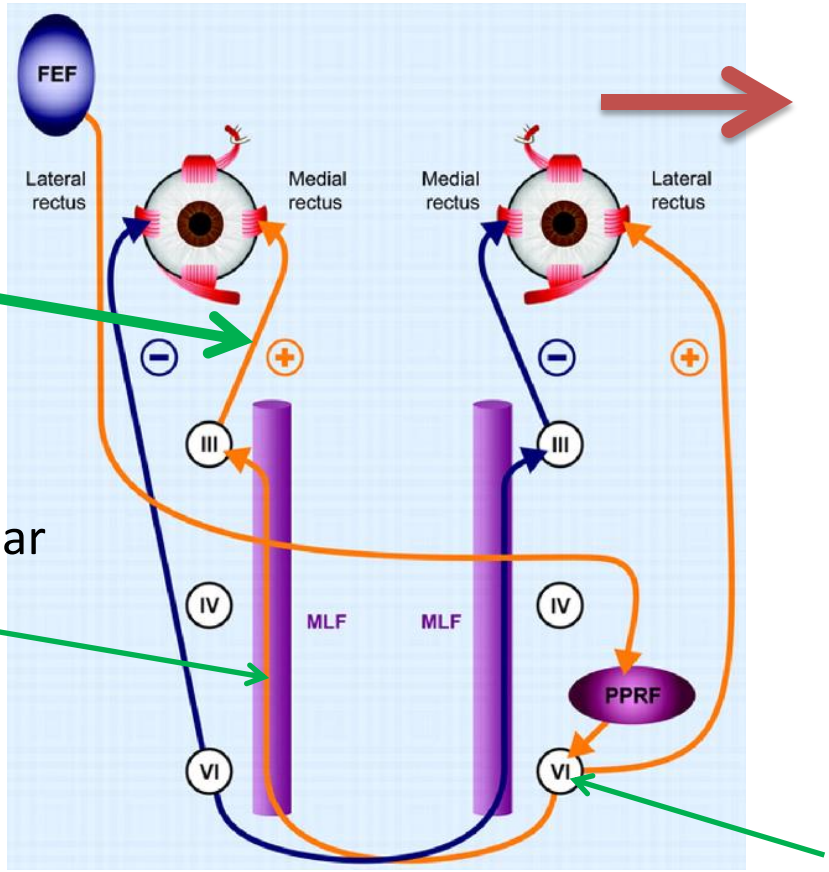

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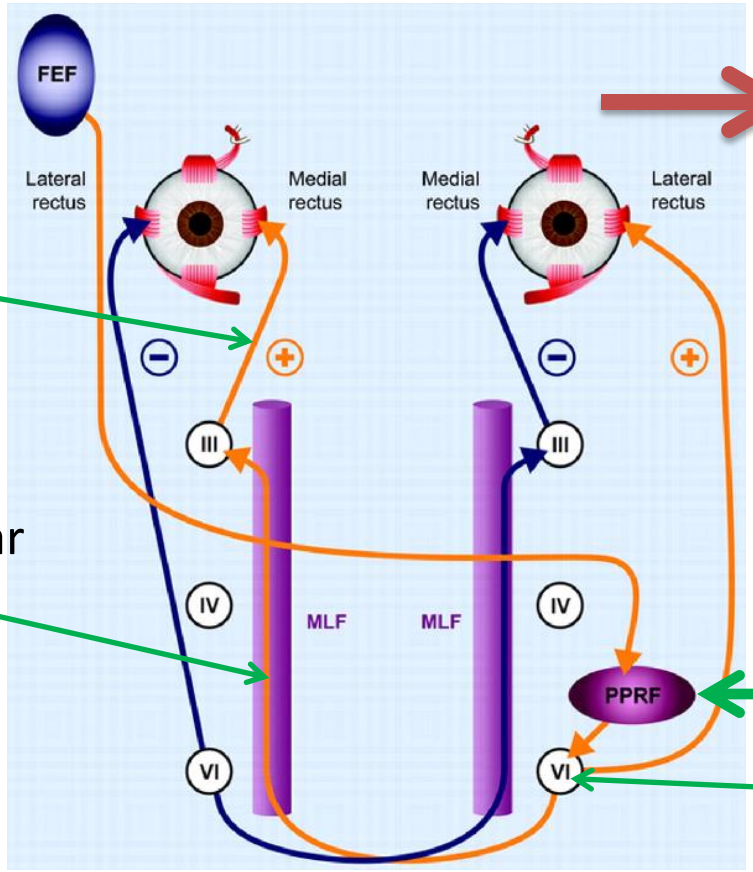

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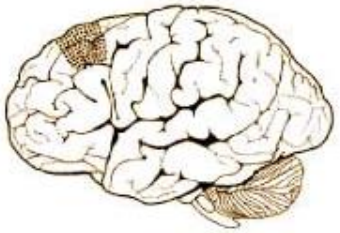
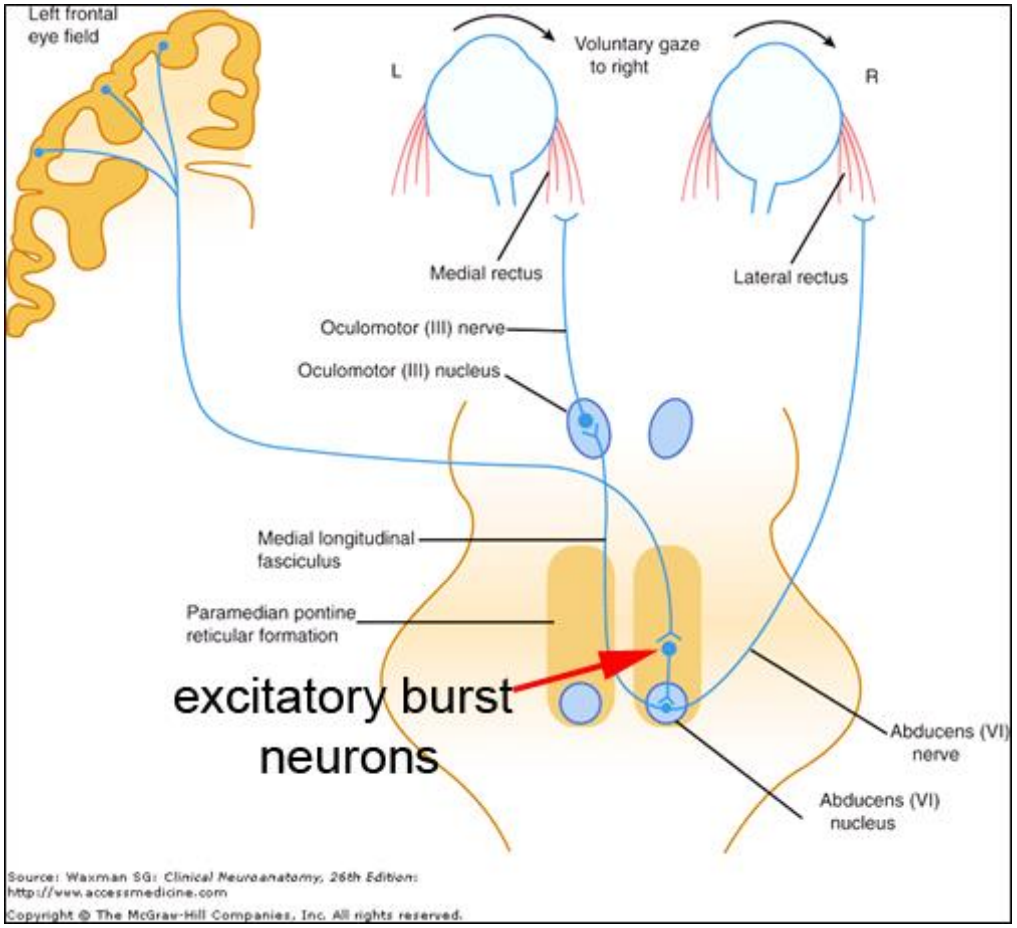
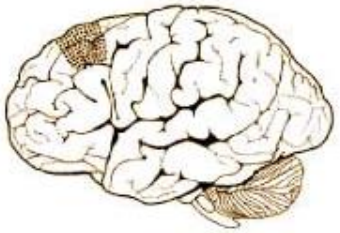
What Brain Region Controls the Motor Neurons in Horizontal Gaze Shift?

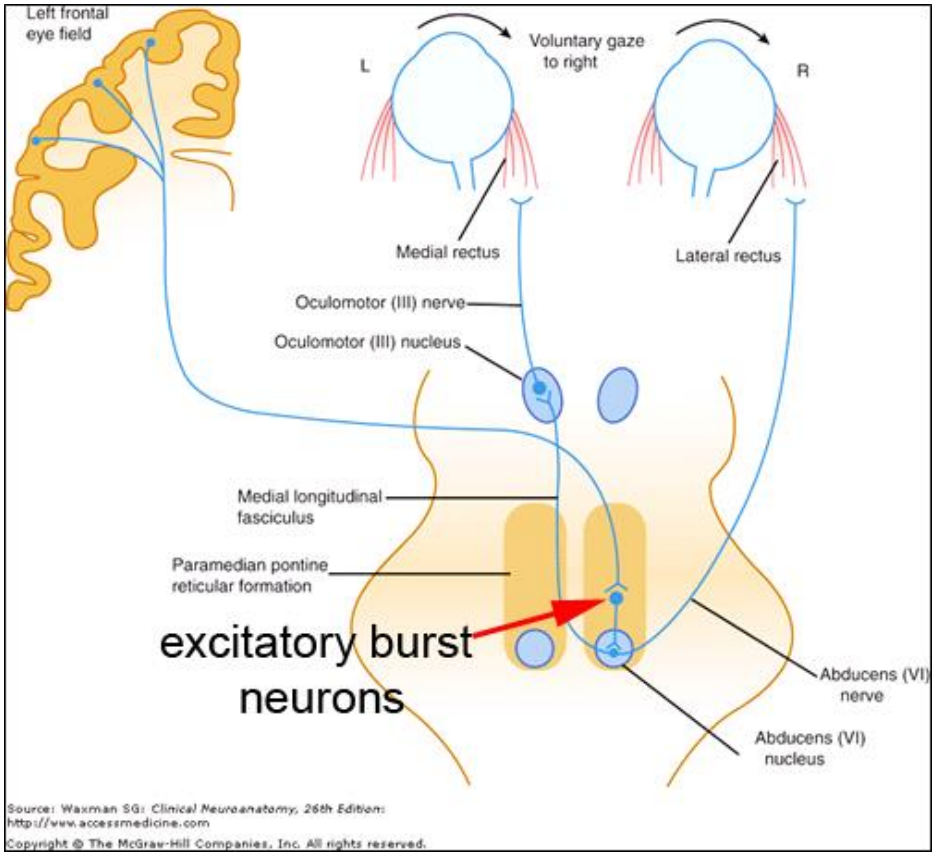




Frontal eye field neurons in the cerebral cortex project to **excitatory burst neurons**, and these project to the motor neurons.

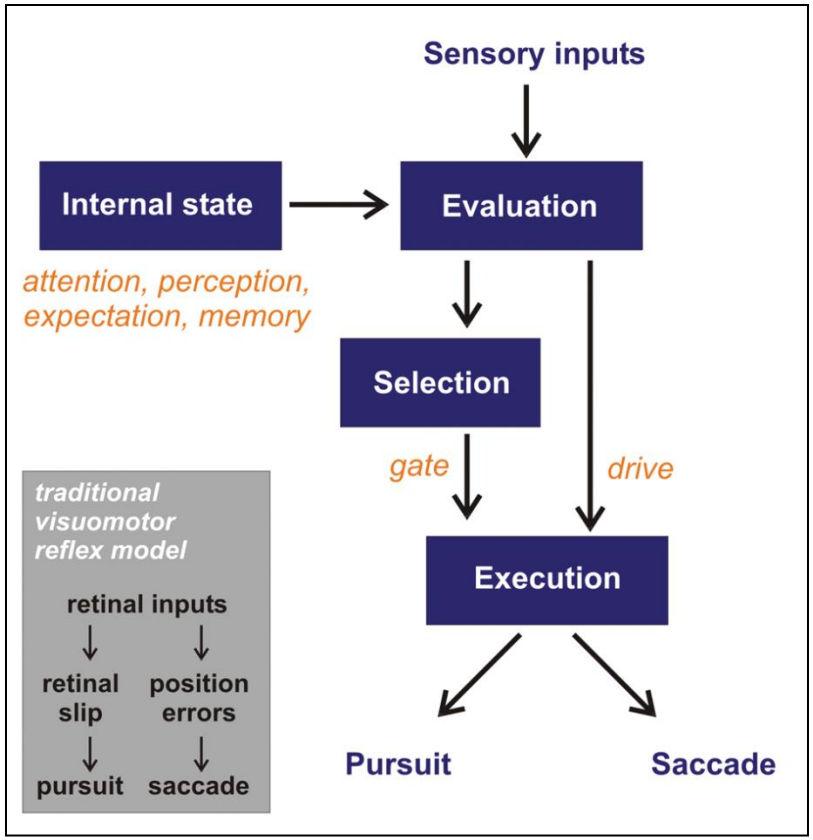
What Brain Region Controls the Motor Neurons in Horizontal Gaze Shift?





Frontal eye field → excitatory burst neurons → abducens motor neurons → internuclear neurons → oculomotor neurons on the contralateral side

Ultimately all eye movements that involve saccades and smooth pursuit are initiated in the cortex.

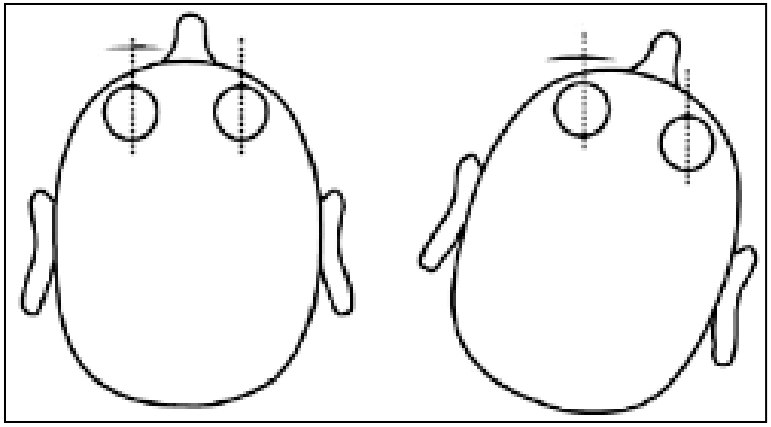


Krauzlis, Neuroscientist 2005

Vertical Eye Movements Are Even More Complicated

Muscle	Primary
Superior rectus	Elevation – eye looks up
Inferior rectus	Depression – eye looks down
Superior oblique	Eye looks down and out
Inferior oblique	Eye looks up and out

Vestibular Ocular Reflex (VOR): Stabilization of Gaze Relative to Head Movement

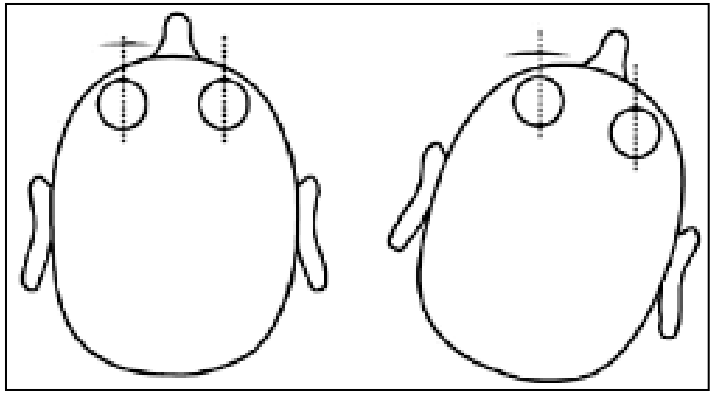


This pathway is activated when you move your head but your eye fixation remains unchanged.

Note that the eyes move in the opposite direction to that of your head, and the image of the visual world remains **stable** despite the head movement.

This is why the world looks stationary despite walking and running.

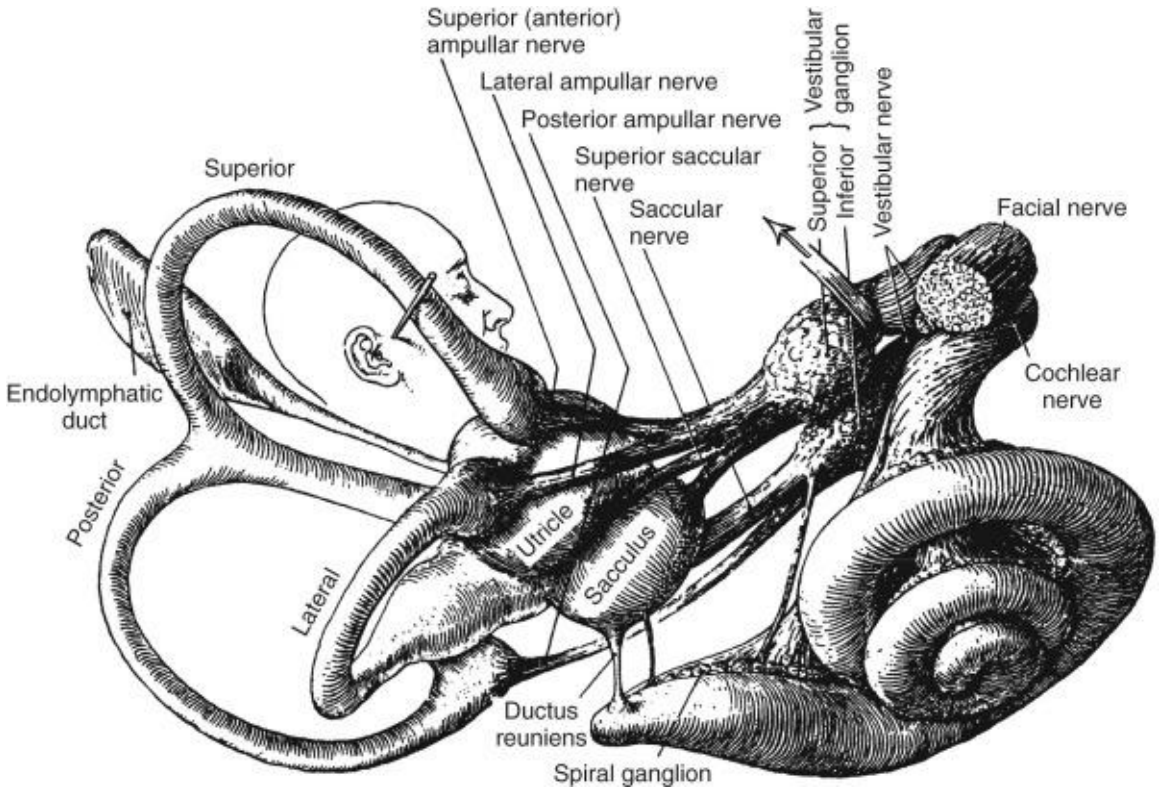
Vestibular Ocular Reflex (VOR): Stabilization of Gaze Relative to Head Movement



If you move a book in front of your stationary head, the text would not be clear. This is because visual processing is much slower than vestibular processing.

The VOR has a very short latency, between 7-15 milliseconds, because it is mediated by only **3 neurons**. It is accurate for velocities in excess of 300 degrees/second.

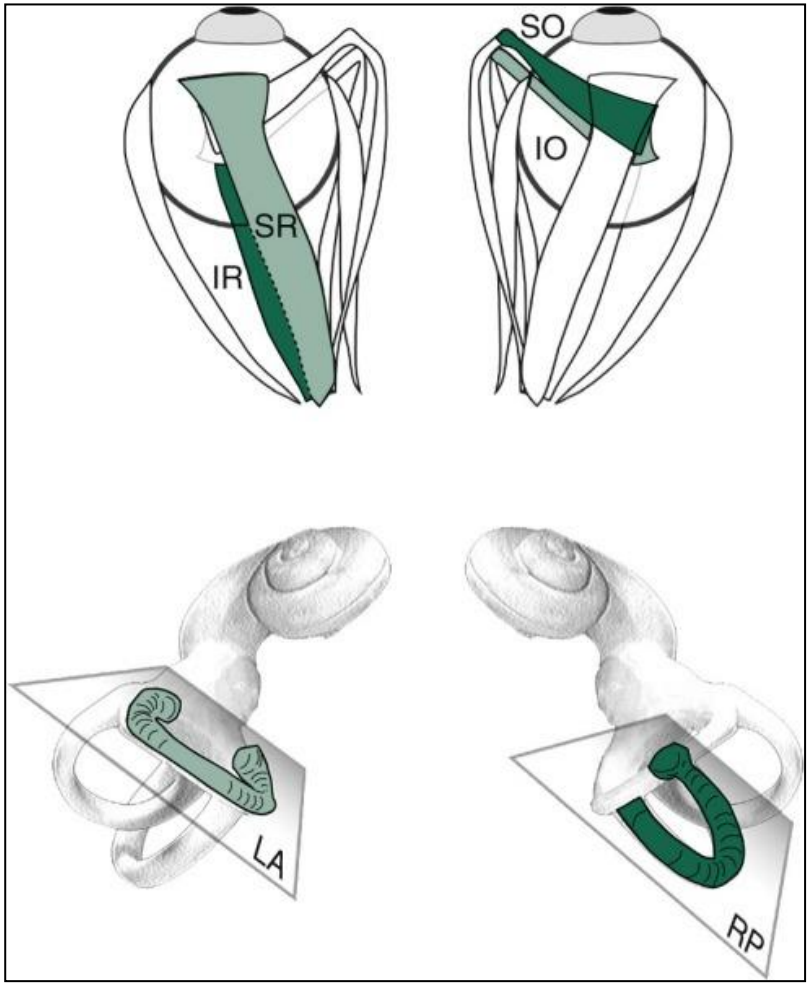
Vestibular Ocular Reflex (VOR): Stabilization of Gaze Relative to Head Movement



The VOR is thanks to your vestibular end organs: three semicircular canals which monitor angular head acceleration and two otolith organs (saccule and utricle) which monitor linear acceleration and head orientation.

Flint, Physiology of the Vestibular System

Vestibular Ocular Reflex (VOR)



The semicircular canals align with the main directions of pull of the extraocular muscles.

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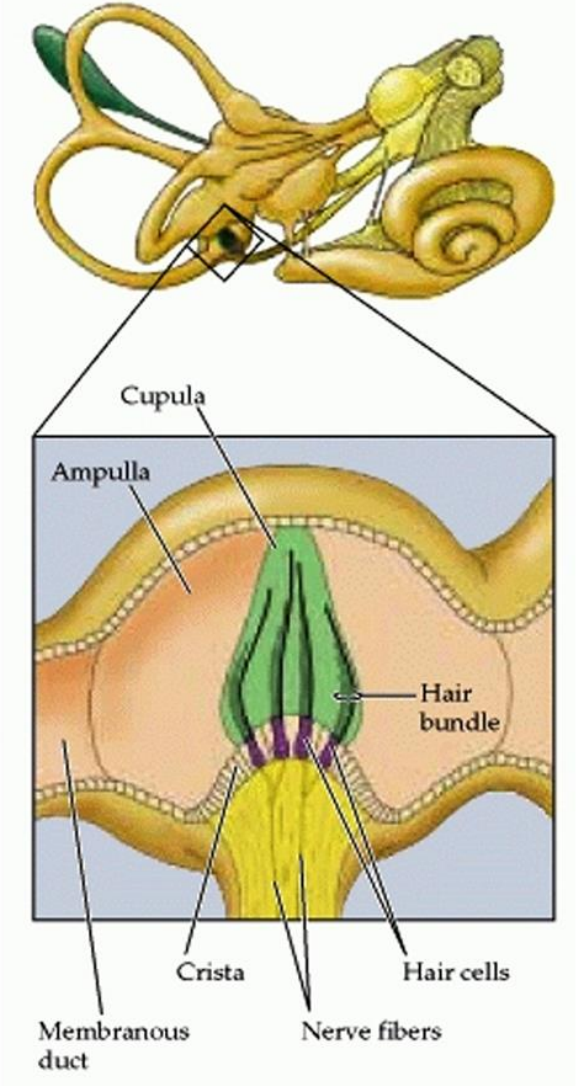
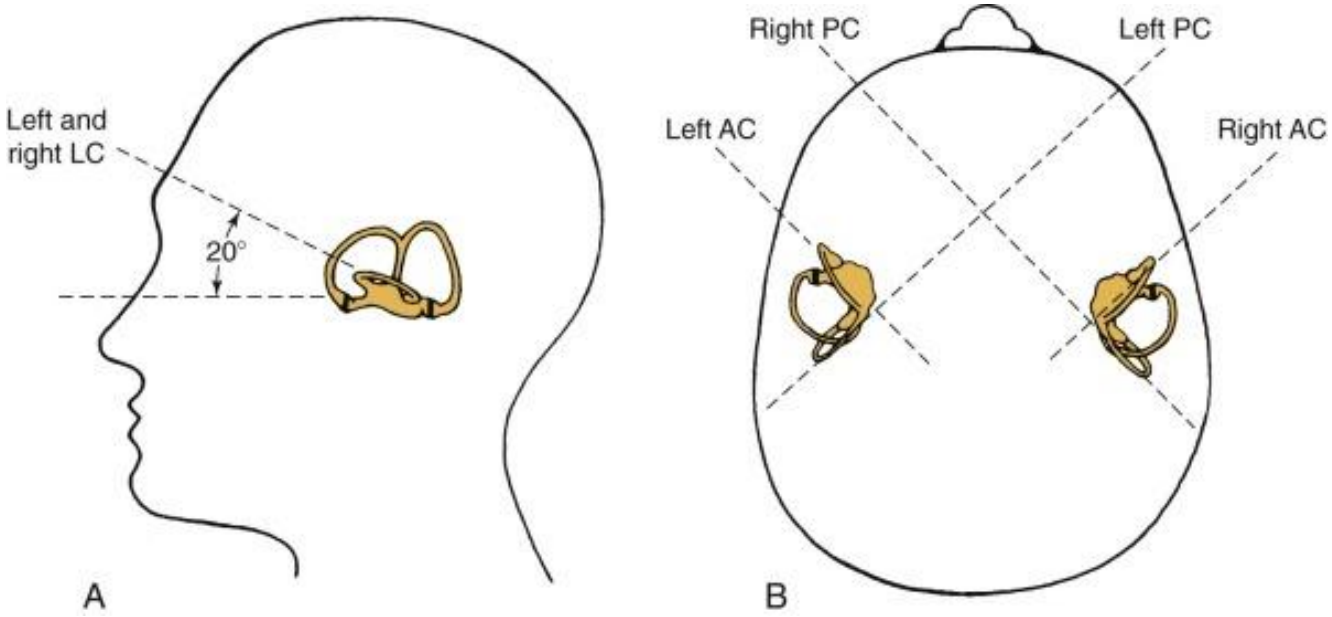
Hair Cells in the Ampule of the Semicircular Canals Detect Angular Acceleration



Purves et al., Neuroscience

Vestibular Ocular Reflex (VOR)



The horizontal canals are in the plane of horizontal muscles (medial and lateral rectus). The hair cells (sensory neurons) located in their ampules send information to the brain about head acceleration.

Each side sends either excitatory or inhibitory information via projections to the vestibular nuclei, which in turn project to the ocular motor nuclei .

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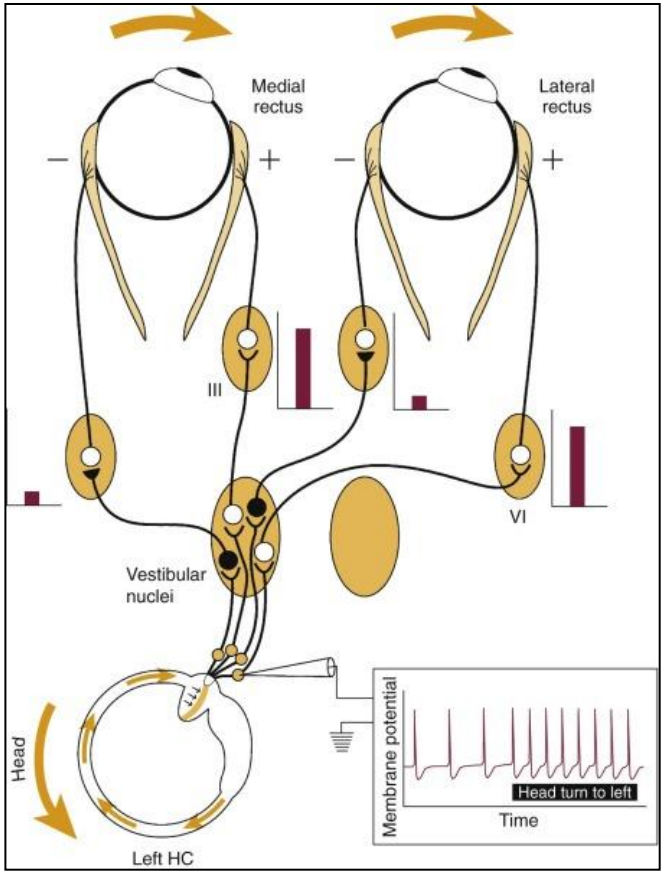
Vestibular Ocular Reflex (VOR): 3 Neuron Arc

3 NEURON ARC



Leftward head movement
Rightward eye movement

Leftward head movement

O excitatory
● inhibitory

Leftward head movement **excites** the **hair cells** in the left horizontal semicircular canal, which send **excitatory** input to the left vestibular nuclear neurons.

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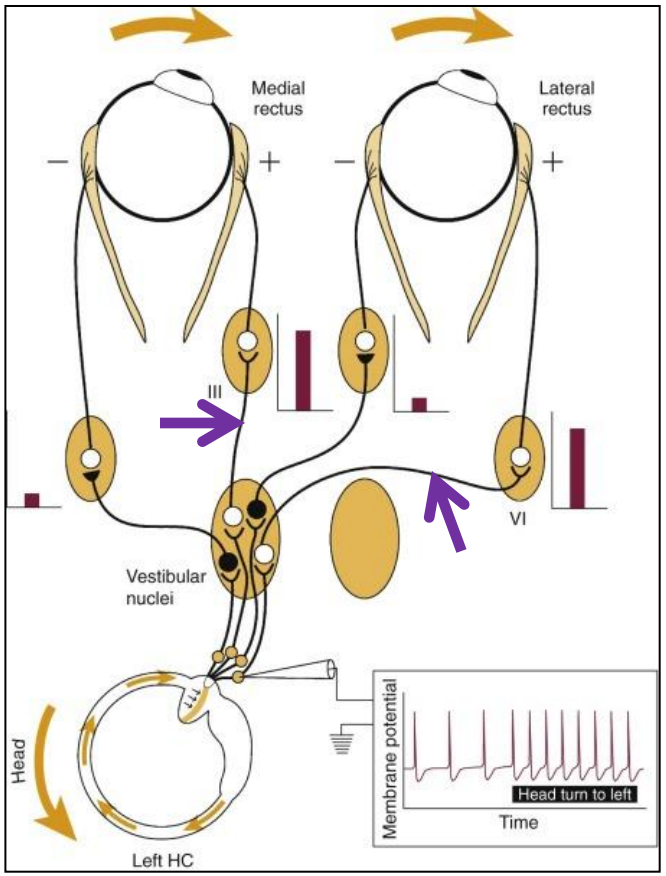
Vestibular Ocular Reflex (VOR): 3 Neuron Arc

3 NEURON ARC



Leftward head movement
Rightward eye movement

Leftward head movement

O excitatory
● inhibitory

Leftward head movement **excites** left horizontal semicircular canal, which send excitatory input to left vestibular nuclear neurons. **These send excitatory signals to left oculomotor nucleus and the right abducens nucleus** and inhibitory signals to the right oculomotor nucleus and the left abducens nucleus.

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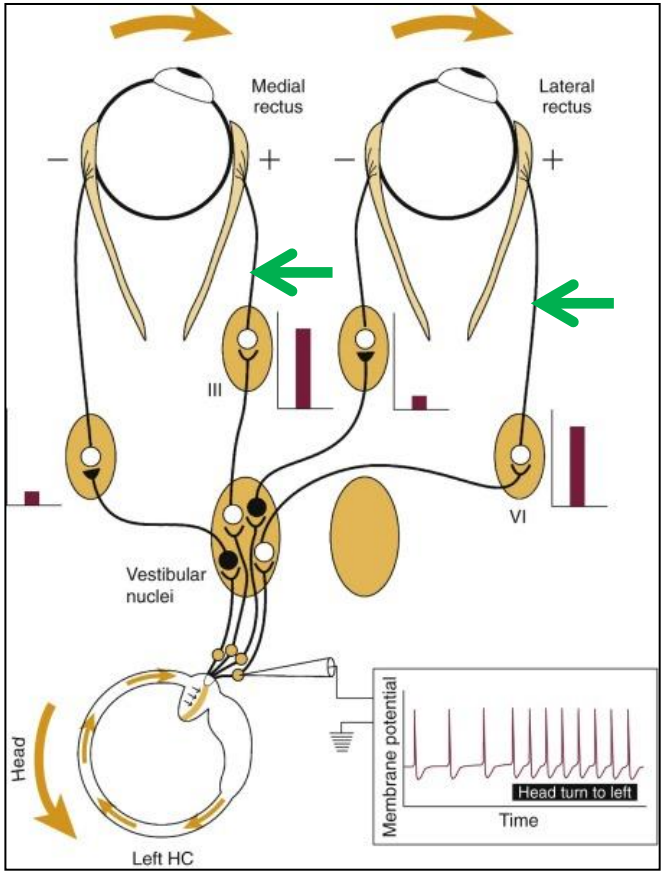
Vestibular Ocular Reflex (VOR): 3 Neuron Arc

3 NEURON ARC



Leftward head movement
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O excitatory
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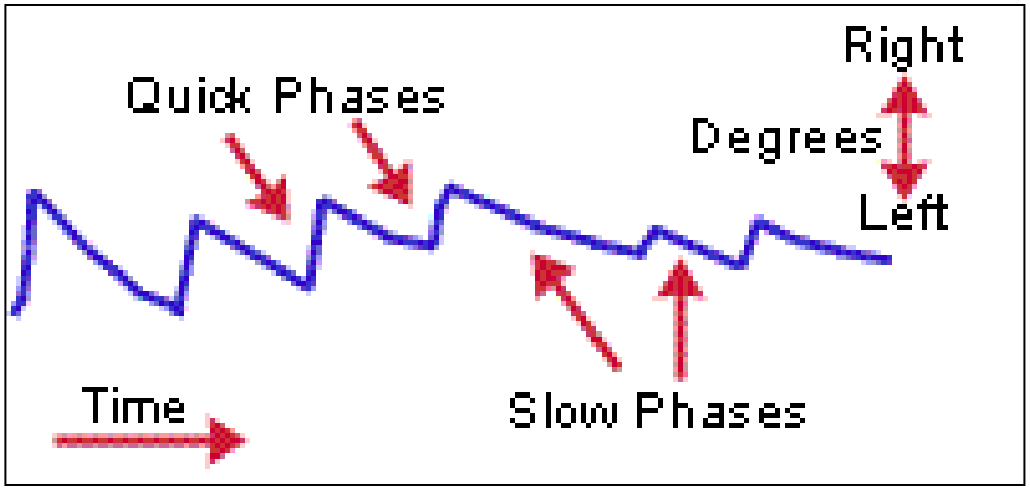
These in turn send **excitatory signals to the left medial rectus and right lateral rectus muscles** and inhibitory signals to the left lateral rectus and right medial rectus muscles.

<u>This pathway is FAST and does not require vision</u>.

Flint, Physiology of the Vestibular System

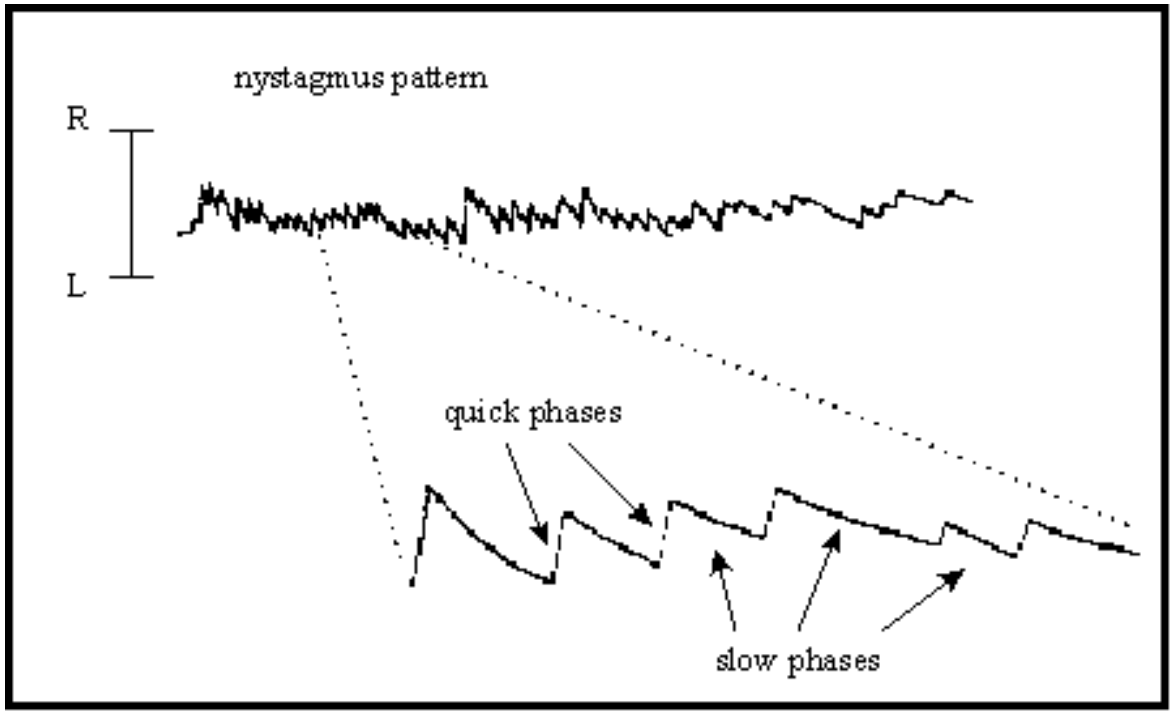
What do your eyes do when you spin around and around?

What if the head moves too fast for the VOR? You get optokinetic nystagmus (OKN).



For clockwise rotational movements, slow phases (when the eye is maintaining gaze) are directed downwards and quick phases (when the eye is resetting) are directed upwards on the eye movement recording above.

Optokinetic Nystagmus Habituates (Decreases) with Continued Rotation

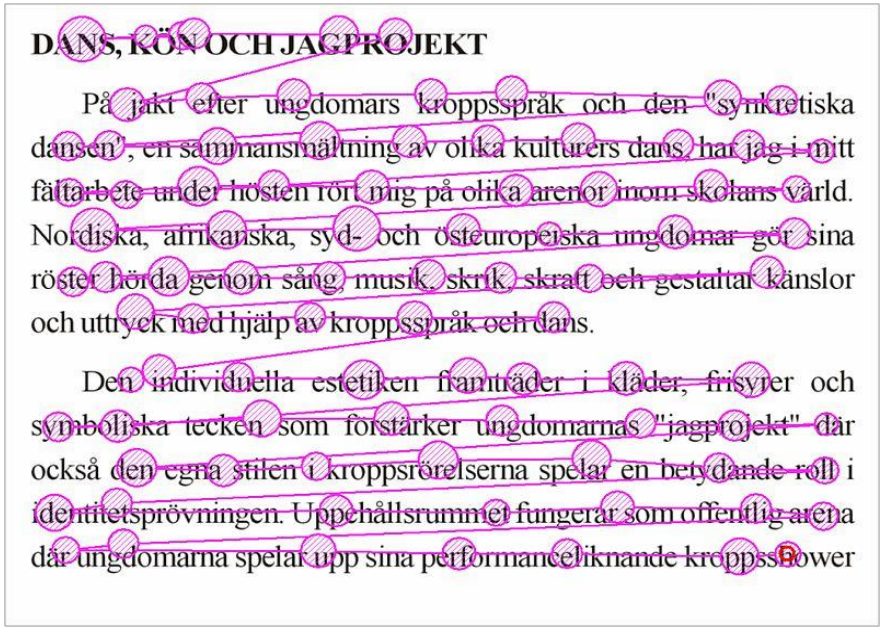


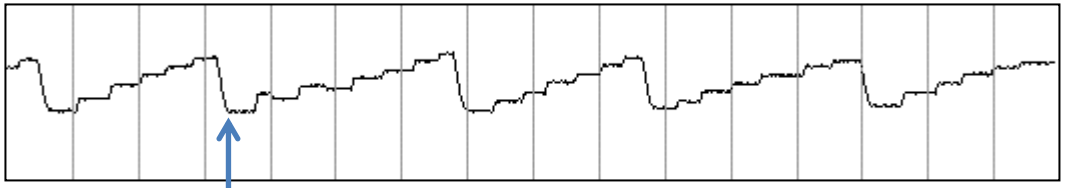
In darkness, the vestibular nystagmus response decays as the semicircular canals (SCC) habituate to a constant rotation (i.e., zero acceleration). Optokinetic nystagmus due to constant rotation in lighted conditions will not decay, due to the continued visual input to the ocular motor system.

The brain is very good at ensuring a stable image reaches the retina.

Have you ever wondered how your eyes move when you are reading?

Eye movements during reading are complex.





New line

In reading, you fixate, make a quick movement (saccade), refixate, make another saccade, etc. We only perceive what we see during the fixation period; no perception is present during saccades.

Summary Questions

What type of movements do your eyes make when you want to change your fixation point in the distance?

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Saccades!

What type of eye movements are made when following a slowing moving object in the visual world and you are stationary?

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Saccades!

What type of eye movements are made when following a slowing moving object in the visual world and you are stationary?
Smooth pursuit!

What type of eye movements are made if you want to look at something close up (like a book)?

What type of movements do your eyes make when you want to change your fixation point?
Saccades!

What type of eye movements are made if an object is moving in the visual world and you are stationary? Smooth Pursuit

What type of eye movements are made if you want to look at something close up (like a book)?
Vergence

The Most Common Disorder of Eye Movements: Strabismus

- 3-5% of children have strabismus.
- There is a critical period during development of binocular vision. Binocular vision must be restored prior to this time (usually by 8-10 years) for normal visual acuity.
- Untreated strabismus can lead to loss of visual acuity in the turned eye, called amblyopia or lazy eye.

Strabismus: Duane's Syndrome

Can be caused by a mutation in the alpha2-chimaerin gene that has been implicated in axon pathfinding.

Leigh and Zee, 2006

Another Common Disorder of Eye Movements: Infantile Nystagmus Syndrome

Involuntary eye oscillations that prevent stable images from forming on the retina

Leigh and Zee, 2006

Questions?

Latent Nystagmus

Leigh and Zee, 2006