The Oculomotor System: Visual Behavior

Why moving our eyes?

High *visual acuity* is restricted to the *fovea*. This is due to the local high density of cones and their low convergence onto ganglion cells as well as to the reduced optical distortion provided by the displacement of the inner nuclear and ganglion cell layers (foveal pit).

Eye movements are therefore used to explore the visual world, as they are necessary to orient the *visual axis* properly so that the images of selected objects or features of interest are brought onto the fovea, where they can be fully analyzed.

Vision is an *active process* in which eye movements shift the view several times each second to selected parts of the scene in order to examine *conspicuous* features. Eye movements allow us to scan the visual field and intermittently focus our *attention* on the parts of the scene that convey the most significant information. The more information is contained in an element, the longer the eyes stay on it. Eye movements reveal a good deal about the strategies used to inspect a visual scene; each scan reflects the intent of the viewer.

Eye movement functions

Eye movements are made either to direct the fovea to new locations (*foveation*) or to compensate for movements of the target of fixation or movements of one's head that caused the visual axis to be displaced (*gaze stabilization*).

They are also essential for normal *visual perception.* We continue to move our eyes even when we stare intently at a stimulus. Such *miniature* eye movements prevent retinal adaptation that causes the visual image to disappear.

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.

Contraction of the medial and lateral recti causes an *adduction* and an *abduction* of the eye, respectively.
Contraction of the superior and inferior recti causes an *elevation* and a *depression* of the eye, respectively.
Contraction of the superior and inferior obliques causes an *intorsion* and an *extorsion* of the eye, respectively.

Types of eye movements

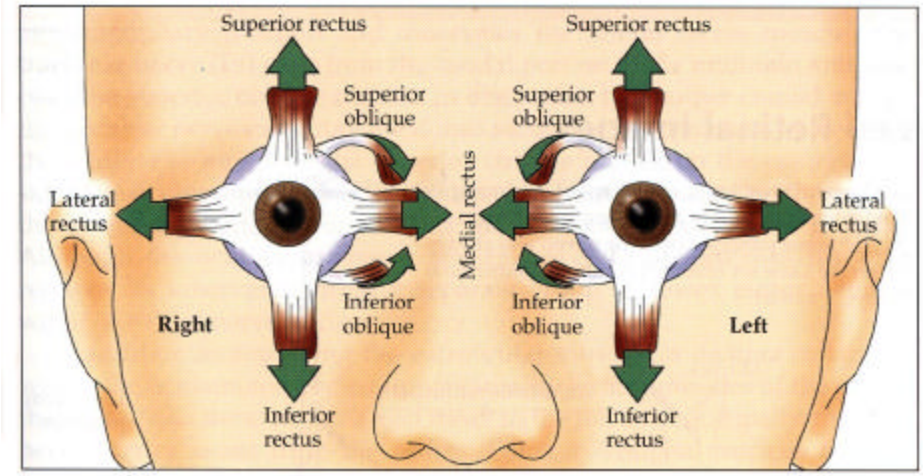
There are four basic types of eye movements.

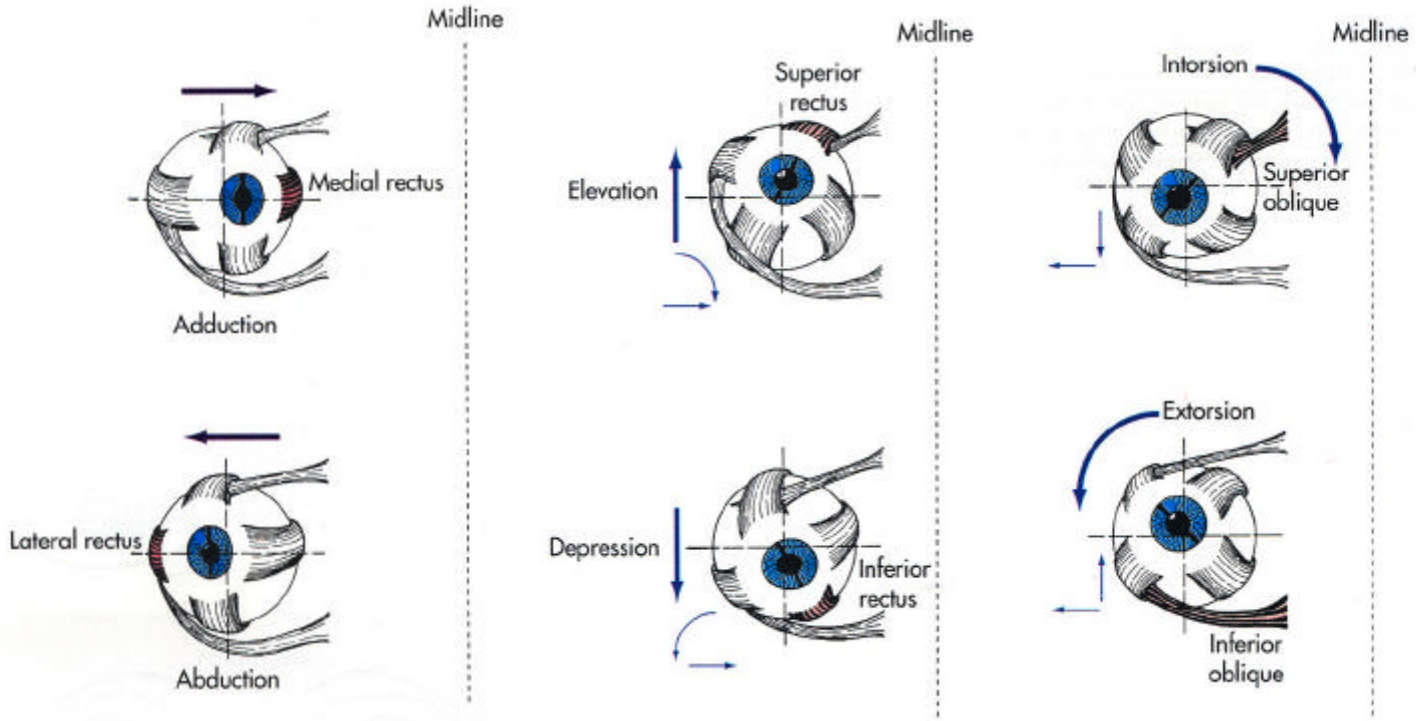
Saccadic eye movements are rapid, ballistic movements of both eyes in the same direction (*conjugate* movements) that abruptly change the gaze fixation position. Their amplitude ranges from miniature eye movements (0.1°) to movements ~40° amplitude from the straight-ahead position. Saccades are made spontaneously in response to a suddenly appearing (or jumping) object. They are also the eye movements produced while we scan a visual scene or read. Thus saccades can be either voluntary or reflexive.

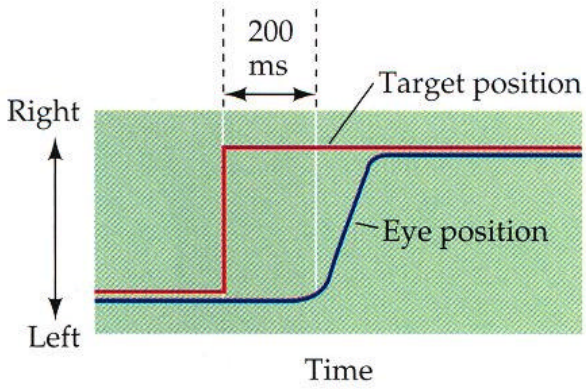
Smooth pursuit eye movements are slow tracking movements of the two eyes designed to keep the image of a moving stimulus on the fovea. Fast moving stimuli cannot be tracked with precision, and they usually elicit saccadic eye movements. The pursuit system needs to compute the speed of the moving stimulus to produce the proper eye velocity. Moving your eyes in this fashion without a moving stimulus is impossible. Pursuit behavior is thus under voluntary control only in the sense that one can chose or not to track a stimulus.

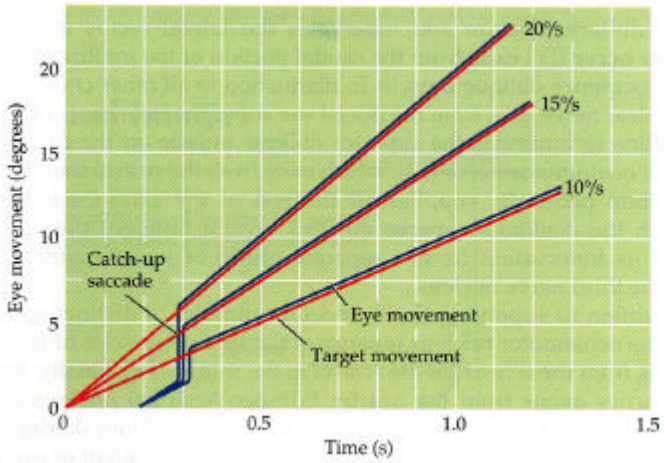
Vergence eye movements align the fovea of each eye with targets located at different distance from an observer. They are *disconjugate* movements, i.e., they move the eyes in opposite direction, producing a convergence or divergence of each eye's visual axis to focus an object that is near or far. *Convergence* is one of the three reflexive responses elicited by a near target. The two other component of this near reflex triad are *accommodation* of the lens, which brings the object into focus, and *pupillary constriction*, which increases the depth of field and sharpens the retinal image.

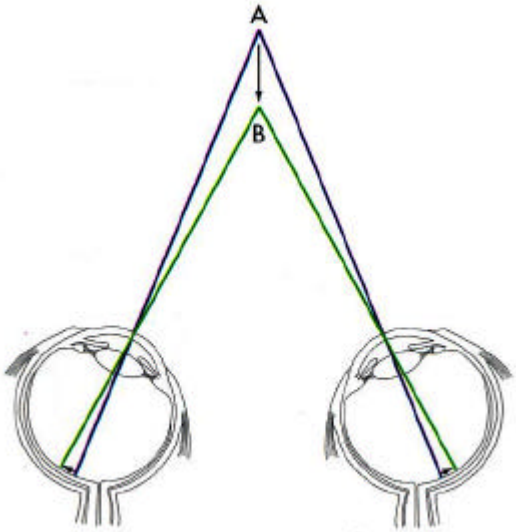
Vestibulo-ocular movements *stabilize* the eyes relative to the external world, *compensating* for head movements. This reflex prevents visual images from "slipping" on the surface of the retina as head position varies. The vestibular system detects brief, transient changes in head position and produces rapid corrective eye movements in a direction opposite to the head movement. Vestibulo-ocular movements also act during coordinated eye-head movements, compensating for the portion of the head movement that lags the more rapid displacement of the eye. This permits the visual axis to remain on the newly foveated stimulus.

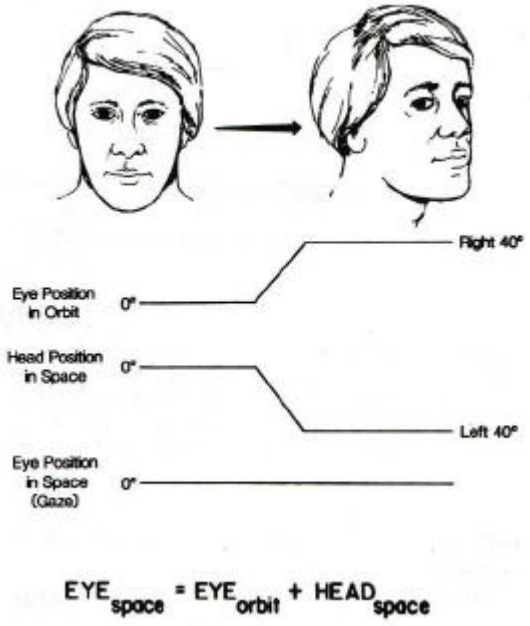

Superior rectus
Superior rectus
Superior oblique
Superior oblique
Lateral rectus
Medial rectus
Lateral rectus
Inferior oblique
Inferior oblique
Right
Left
Inferior rectus
Inferior rectus


Midline
Midline
Midline
Medial rectus
Adduction
Superior rectus
Elevation
Intorsion
Superior oblique
Lateral rectus
Abduction
Depression
Inferior rectus
Extorsion
Inferior oblique


200
ms
Target position
Right
Eye position
Left
Time


20°/s
15°/s
10°/s
Eye movement (degrees)
Catch-up
saccade
Eye movement
Target movement
0
5
10
15
20
0
0.5
1.0
1.5
Time (s)


A
B


Right 40°
Eye Position
in Orbit
0°
Head Position
in Space
0°
Left 40°
Eye Position
in Space
(Gaze)
0°
EYE space = EYE orbit + HEAD space