I. Orbital Geometry

Ball and virtual socket

II. Muscle Mechanics

A. Three Muscle planes

- **Horizontal movers**
- **Vertical movers**
- **Muscles have Primary, Secondary and Tertiary actions**

B. Muscle pairings

III. OCULOMOTOR BEHAVIOR

A. Hering's Law

B. Donders' Law

C. Listing's Law

D. Sherrington's Law of reciprocal innervation

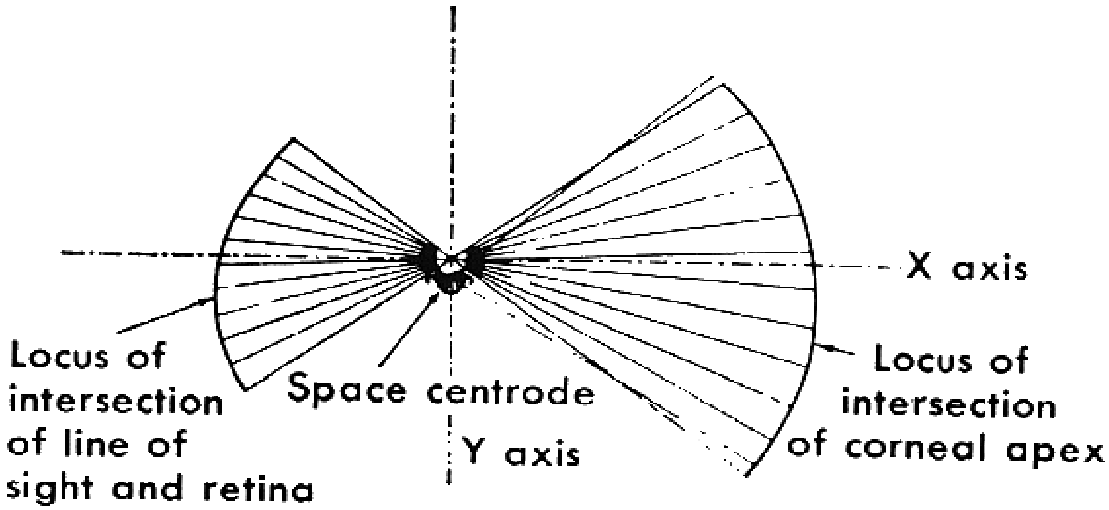
IV. FINAL COMMON PATHWAY HANDOUT

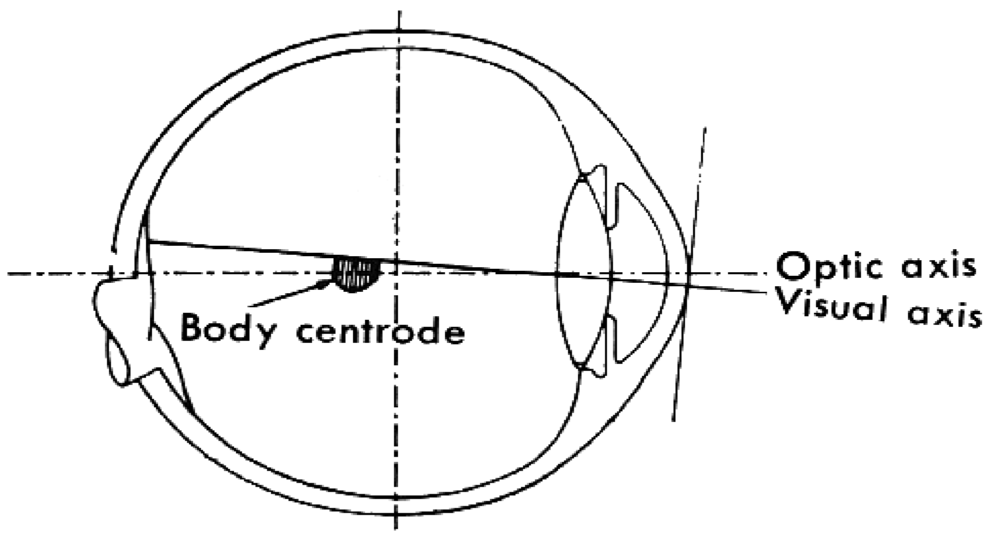
Muscle Efferents - Cranial Nerves III, IV, VI

The Laws of ocular motility

Euler
Donders
Listing
Sherrington
Hooke
Hering

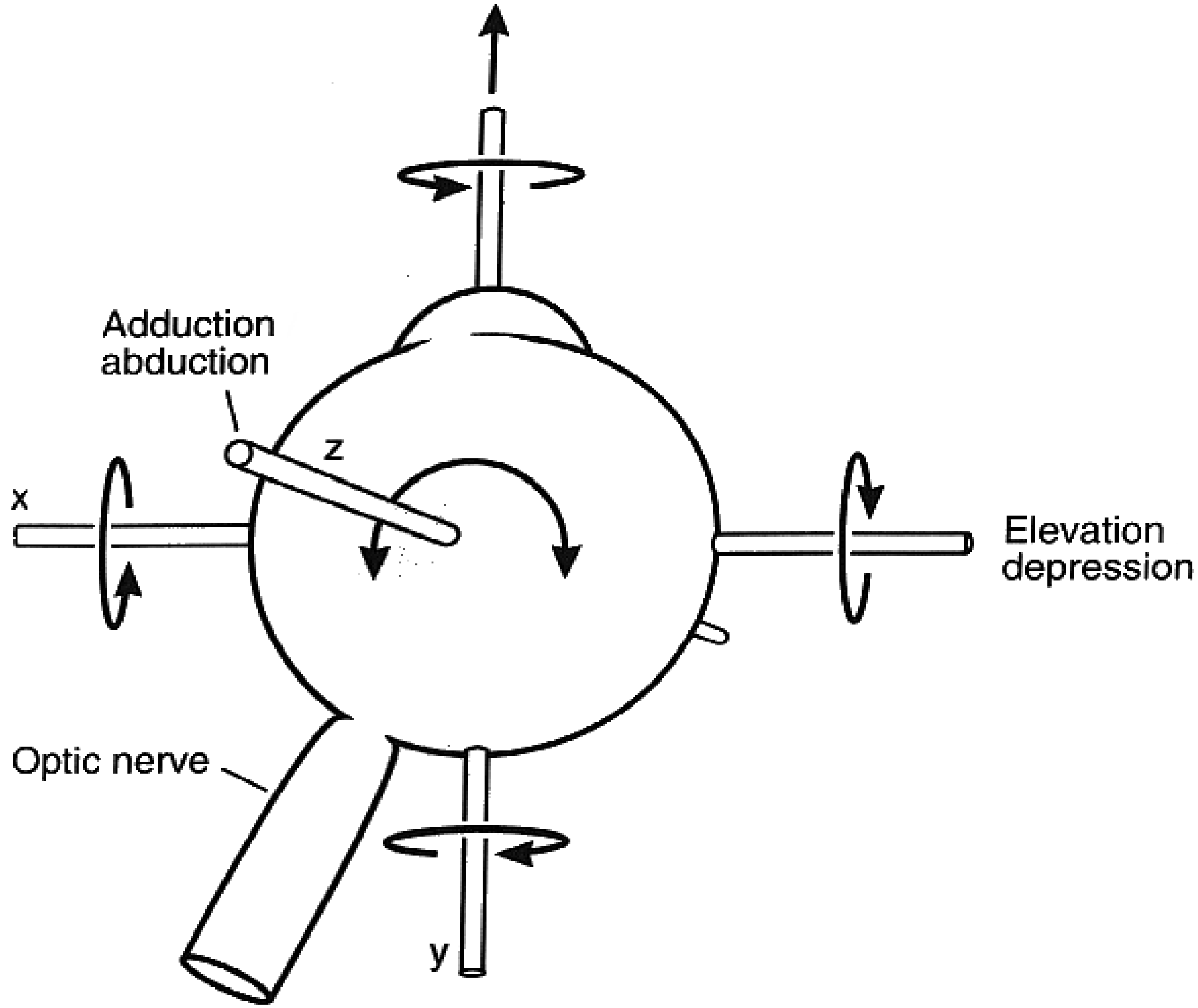
Center of Rotation:





Ball and virtual socket

Describe eye rotation about 3 independent axes (X,Y, Z)
Three degrees of Freedom



Horizontal (Z) , Vertical (X) and Cyclotorsion (Y)

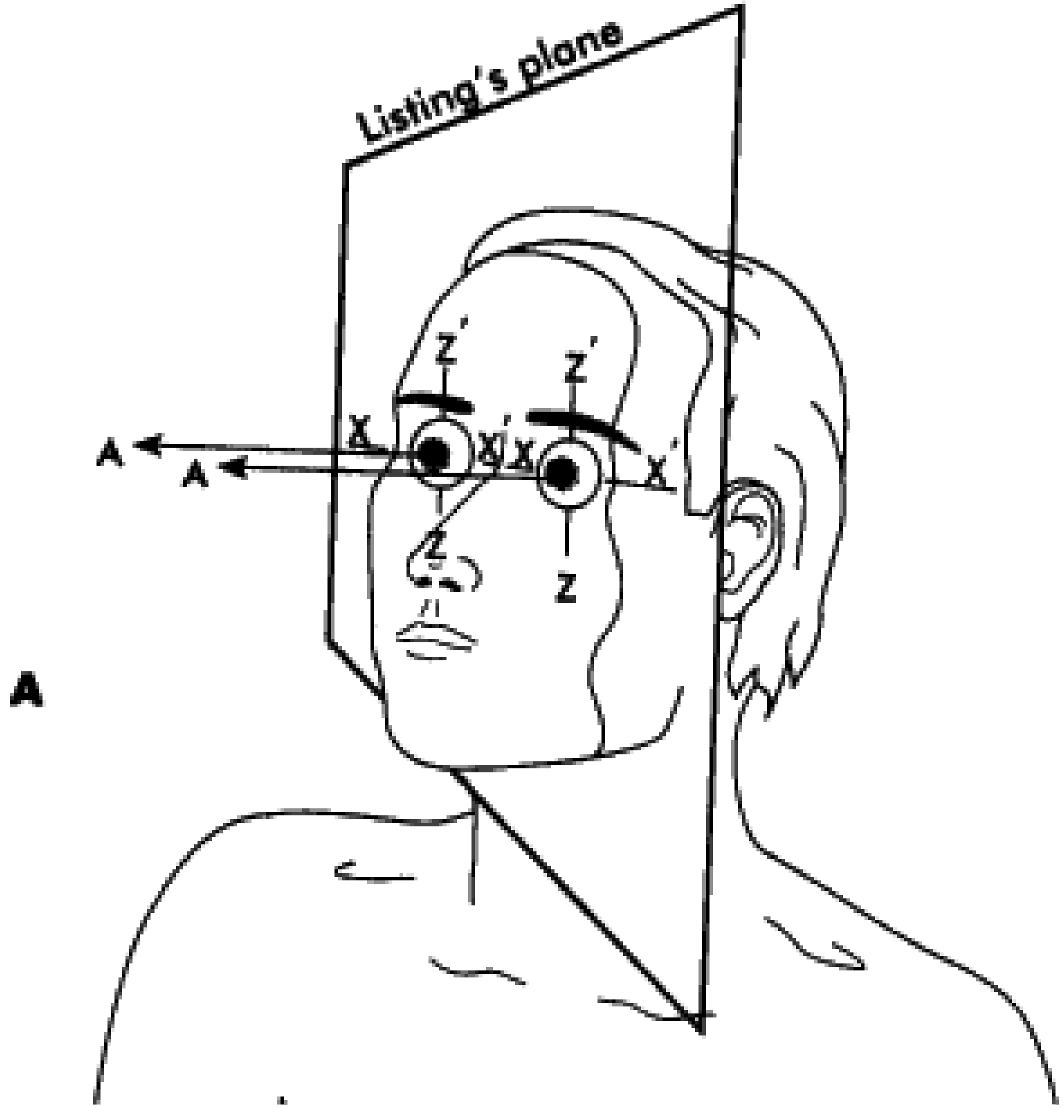
Euler's rule: There are an *infinite* number of axes of rotation that can change gaze from one direction to another, however each axis produces a unique torsion. (demo with tennis ball)

Donder's law states that the torsion of the eye in any direction of gaze is independent of the the sequence of horizontal and vertical rotations used to reached that gaze direction.

Implication: This means that there is only one axis of rotation that can describe eye orientation in a given direction of gaze.

Listing's law predicts the amount of torsion in any direction. Its *as though* the eye rotated from primary position about an axis that was constrained to lie in the fronto-parallel plane (Listing's plane)

All axes of rotation that rotate the eye from primary position lie in a single plane (Listing's Plane)



Listing's demonstration animation

Listing's law simplifies eye rotations. It reduces degrees of freedom from 3 to 2 by constraining all axes of rotation from primary position to lie in a single plane.

This means that only one axis of rotation is used to describe a particular direction of gaze and that axis must lie in Listing's plane.

Then, following Euler's rule, we only need to control horizonal and vertical components of gaze direction. Torsion about the line of sight will be determined automatically by the axis of rotation.

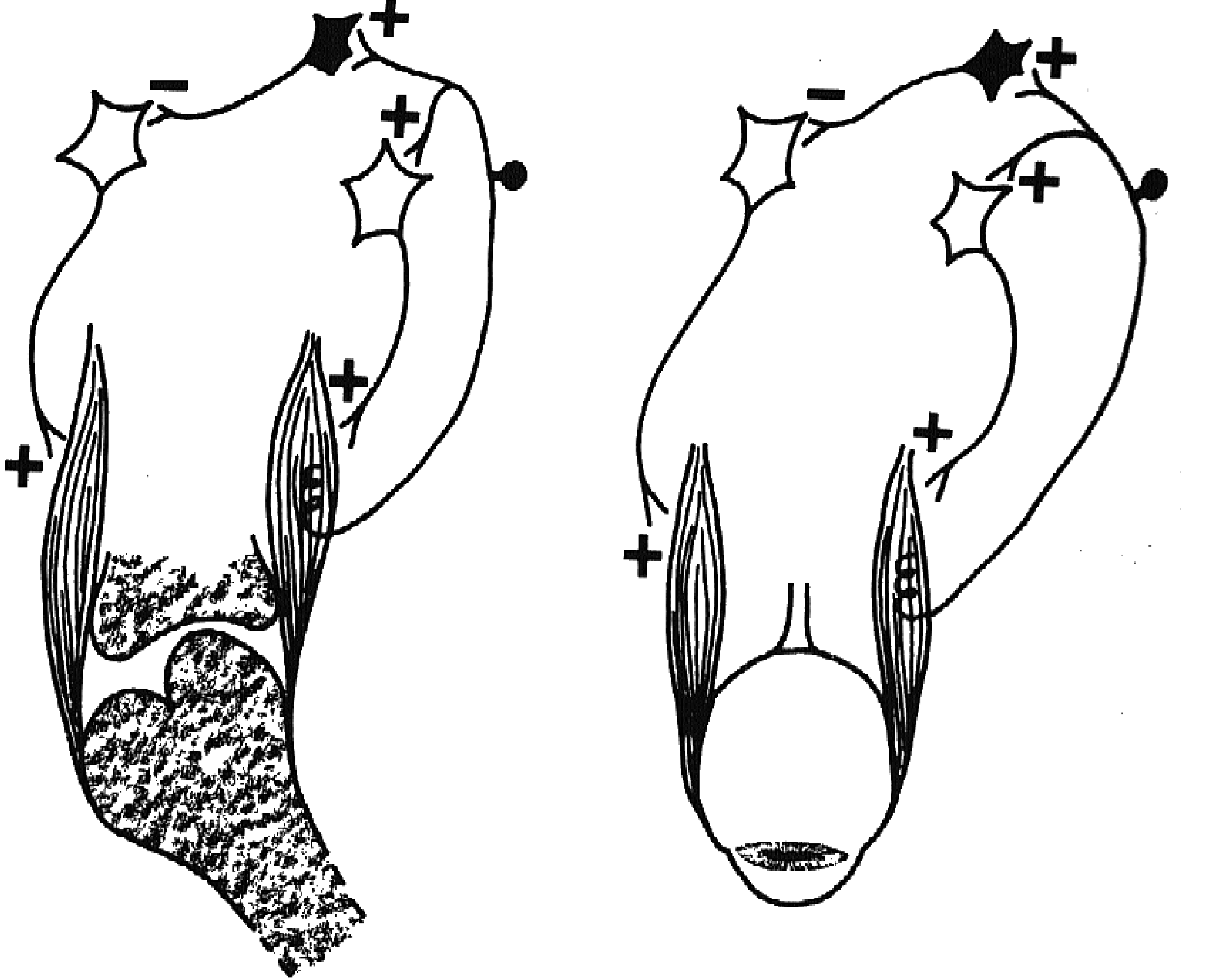
Play the Listing's law demonstration program from Germany

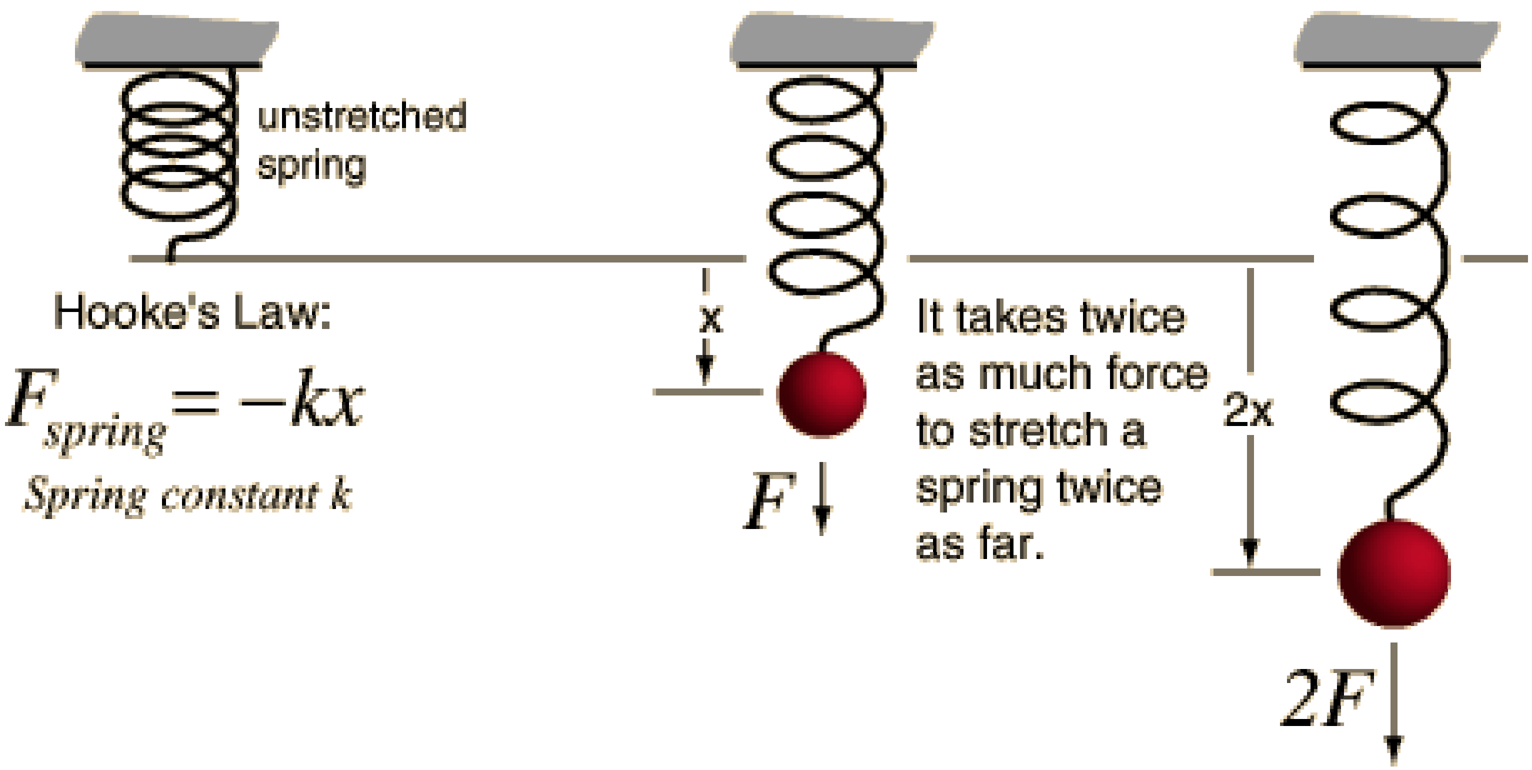
Agonist and antagonist pairs work with push-pull (opponent) actions.

Sherrington's law of reciprocal innervation:

Increased innervation to the agonist is associated with decreased innervation of the antagonist.

Sherrington's law of reciprocal innervation.





Muscle innervation increases the spring constant (K) or muscle stiffness. This increases the restoring force applied to the eye and antagonist muscle.

Hooke's Law: Force exerted by a spring equals the product of its length (L) and spring-stiffness constant (K) or elasticity.

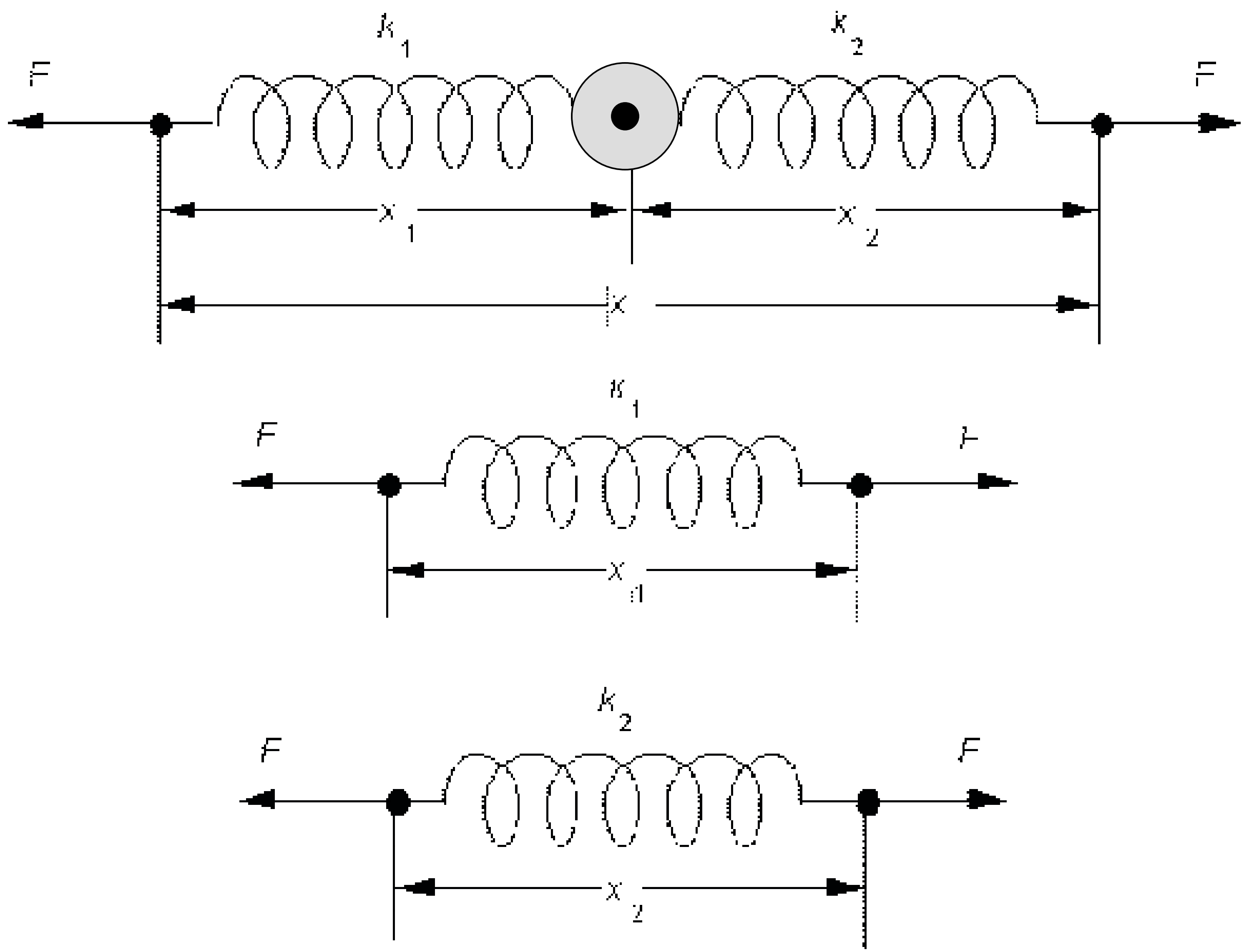
$F = L \times K$

Innervation increases the spring stiffness and force of the agonist against the antagonist.

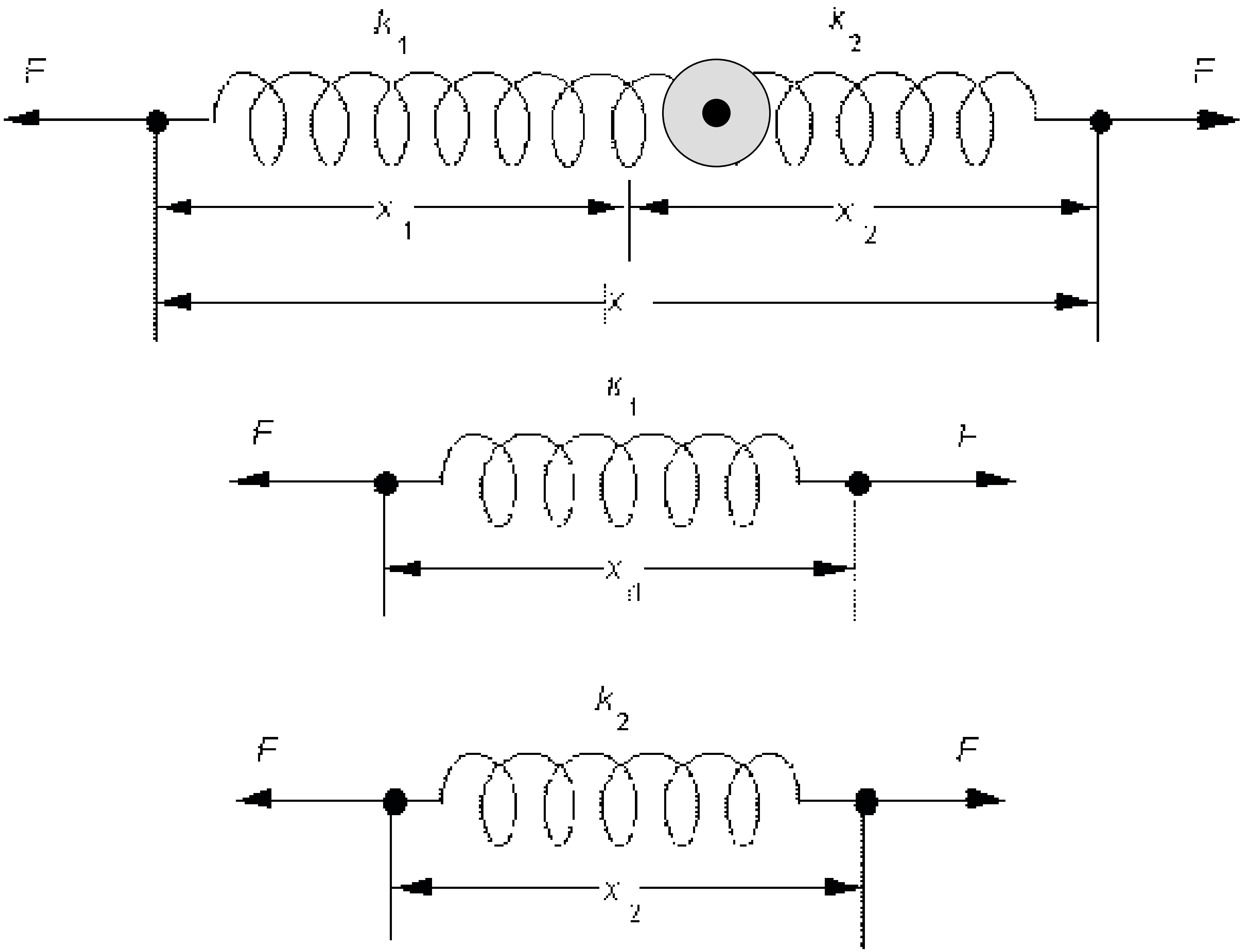
The length of the antagonist increases when stretched by the agonist until their forces become equal.

Force exerted by the agonist and antagonist is smallest in primary position.

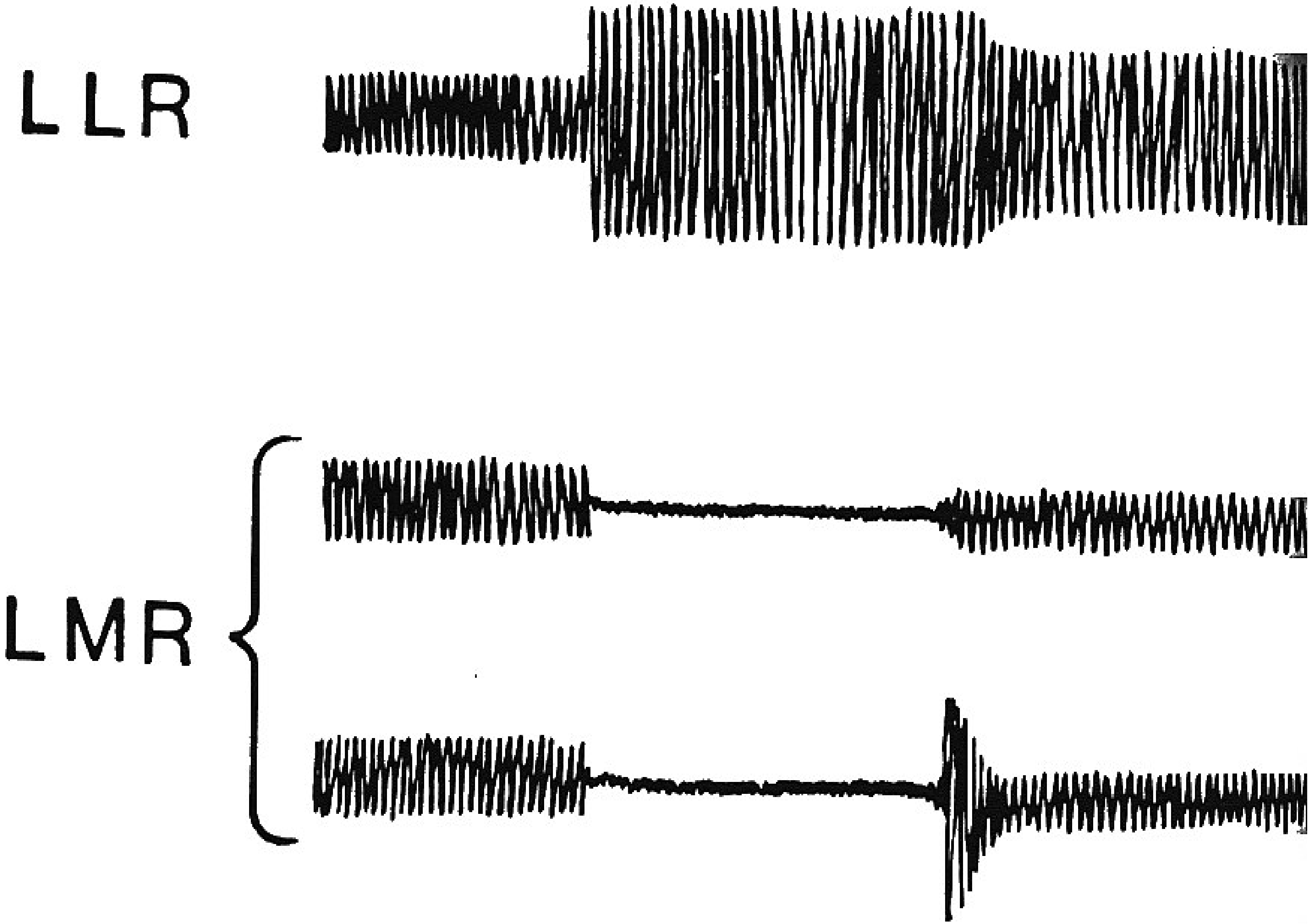
$$X_1 * K_1 = F = X_2 * K_2$$



$$X_1 * K_1 = F = X_2 * K_2$$

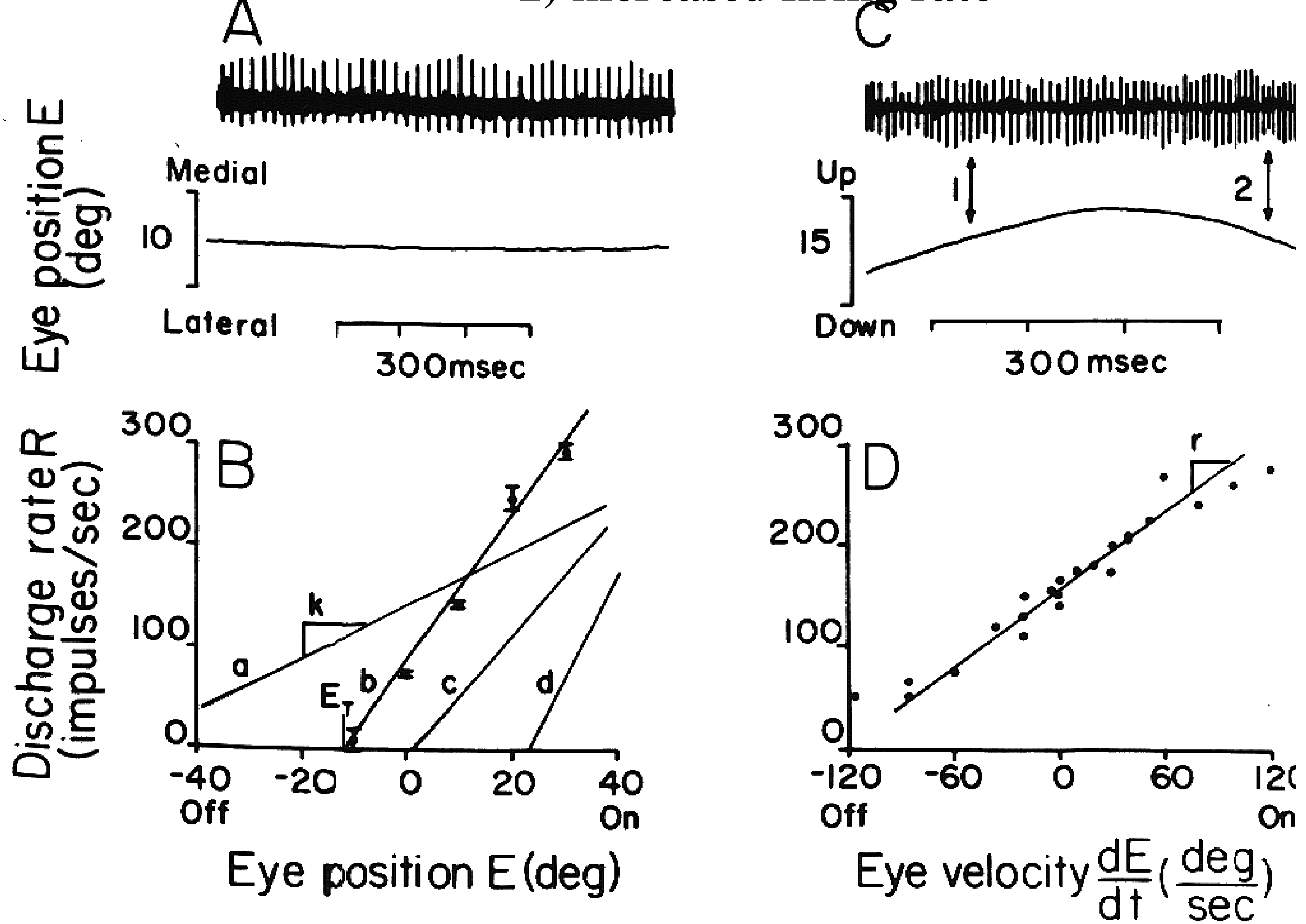


Neural implementation of Sherrington's law.



Position-rate firing curve. Two ways to increase innervation & force

1) recruitment
2) increased firing rate



Hering's Law: Figurative definition.

There is equal innervation of yoked muscle pairs.

"one and the same impulse of will directs both eyes simultaneously as one can direct a pair of hoses with single reins."

Literally, the yoked muscles receive different innervation, but they rotate the two eyes the by same amount.

Terms:

Version and Vergence are two separate forms of control.
Version AKA Yoked

Yoked muscle pairs in the two eyes move them in the same direction.
e.g. LLR & RMR

Agonist muscles move the eye in the desired direction.
e.g. LLR & RMR for leftward eye rotation

Antagonist muscles oppose the action of agonist muscles in the same eye.
e.g. LMR and RLR oppose leftward eye rotation

Agonist and antagonist muscle pairs in one eye share a common plane.

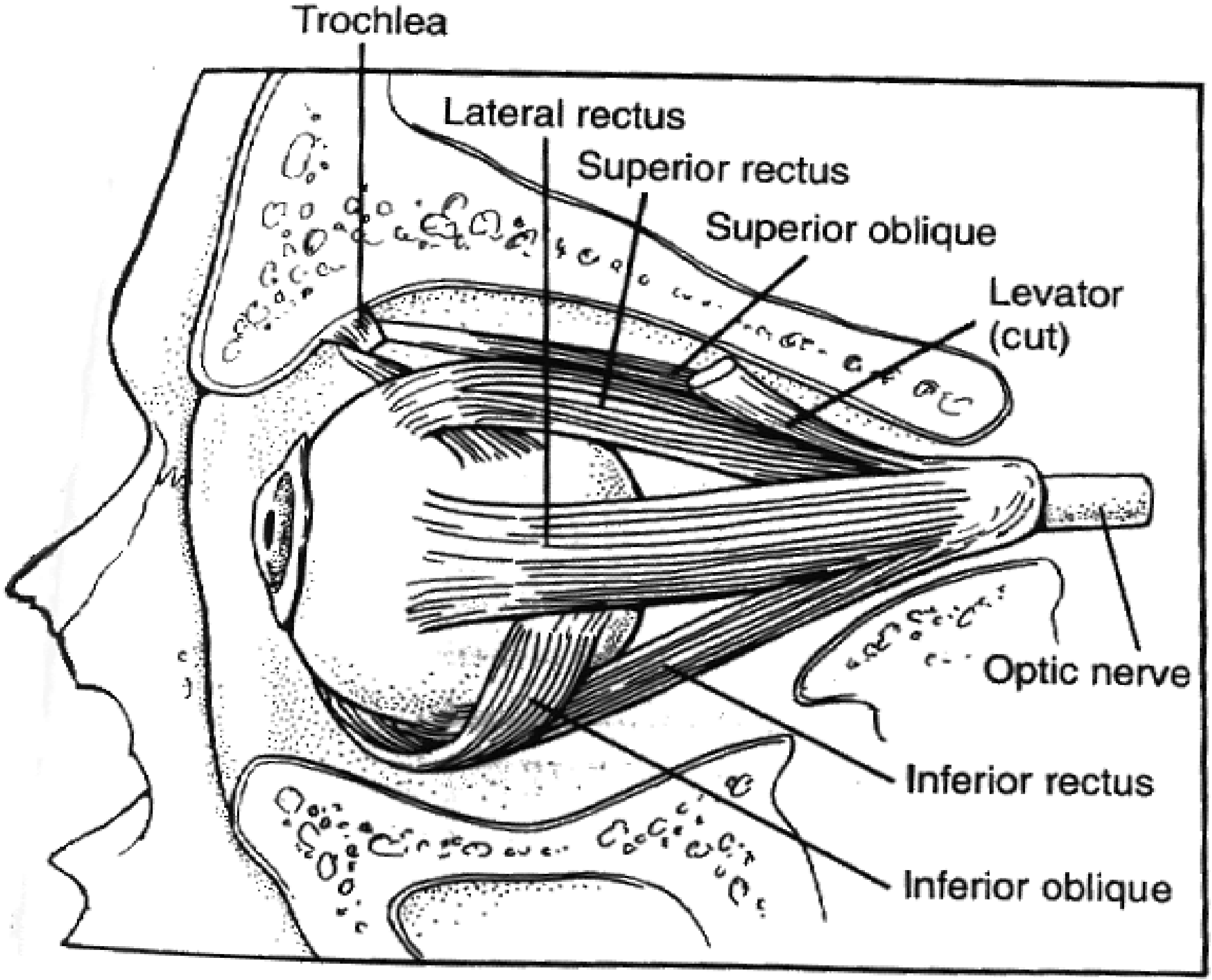
Adduction- Nasal-ward (inward) eye rotation

Abduction- Temporal-ward (outward) eye rotation

Mechanics: Plant structure & organization

Muscles, origins & insertions determine actions

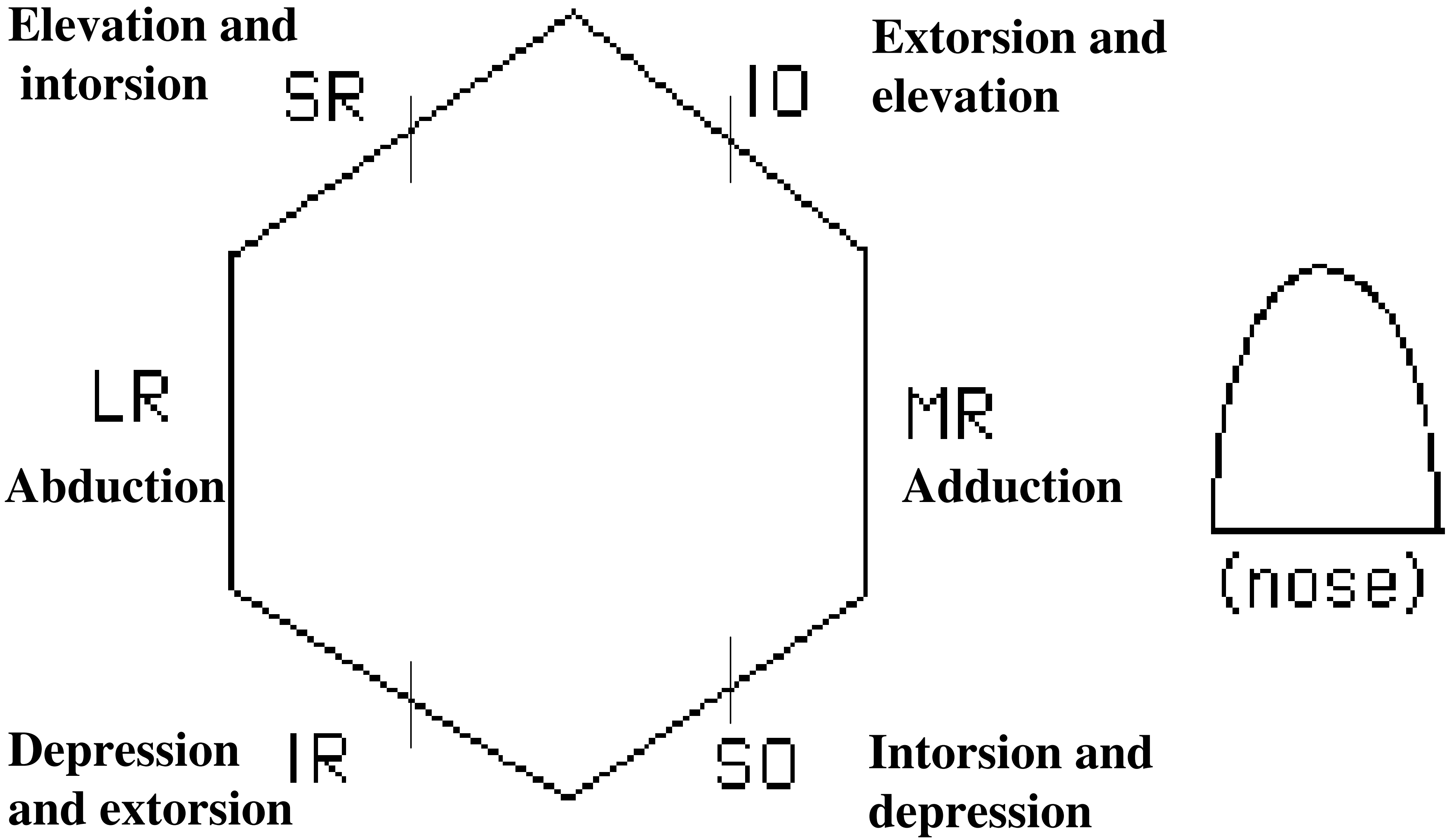
Anatomical origins and insertions of six extra-ocular muscles



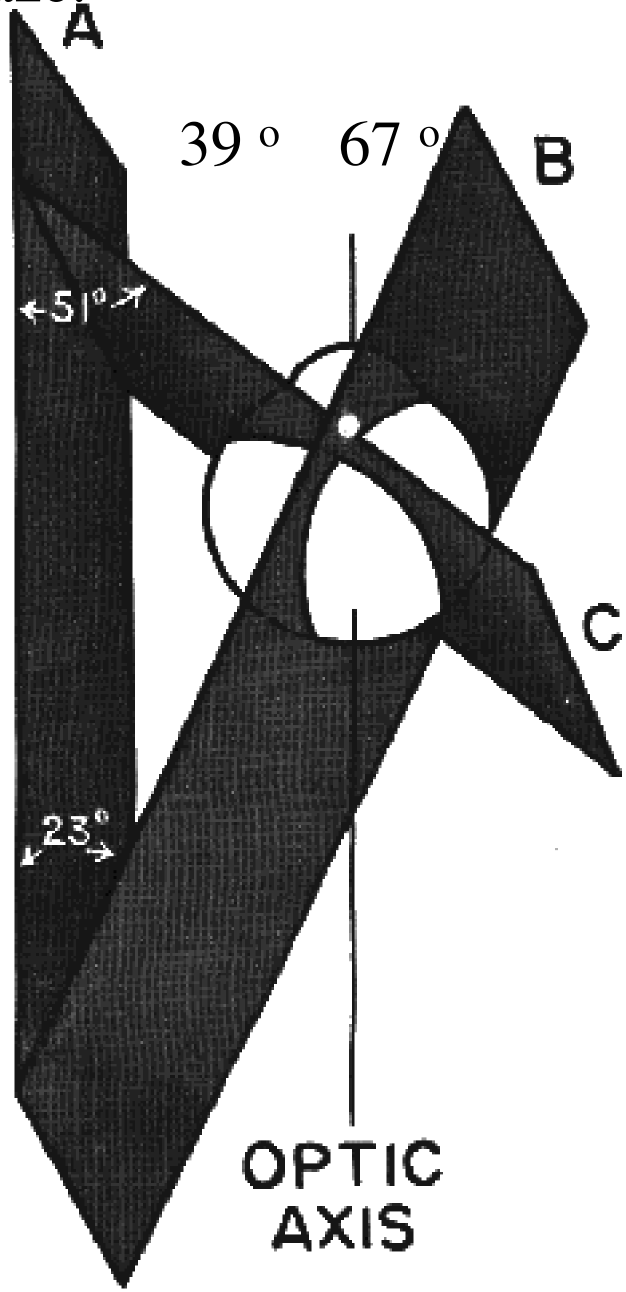
Primary, Secondary, and Tertiary Actions of the Extraocular Muscles from the Primary Position

Muscle	Primary Action	Secondary Action	Tertiary Action
Medial rectus	Adduction	—	—
Lateral rectus	Abduction	—	—
Inferior rectus	Depression	Excycloduction	Adduction
Superior rectus	Elevation	Incycloduction	Adduction
Inferior oblique	Excycloduction	Elevation	Abduction
Superior oblique	Incycloduction	Depression	Abduction

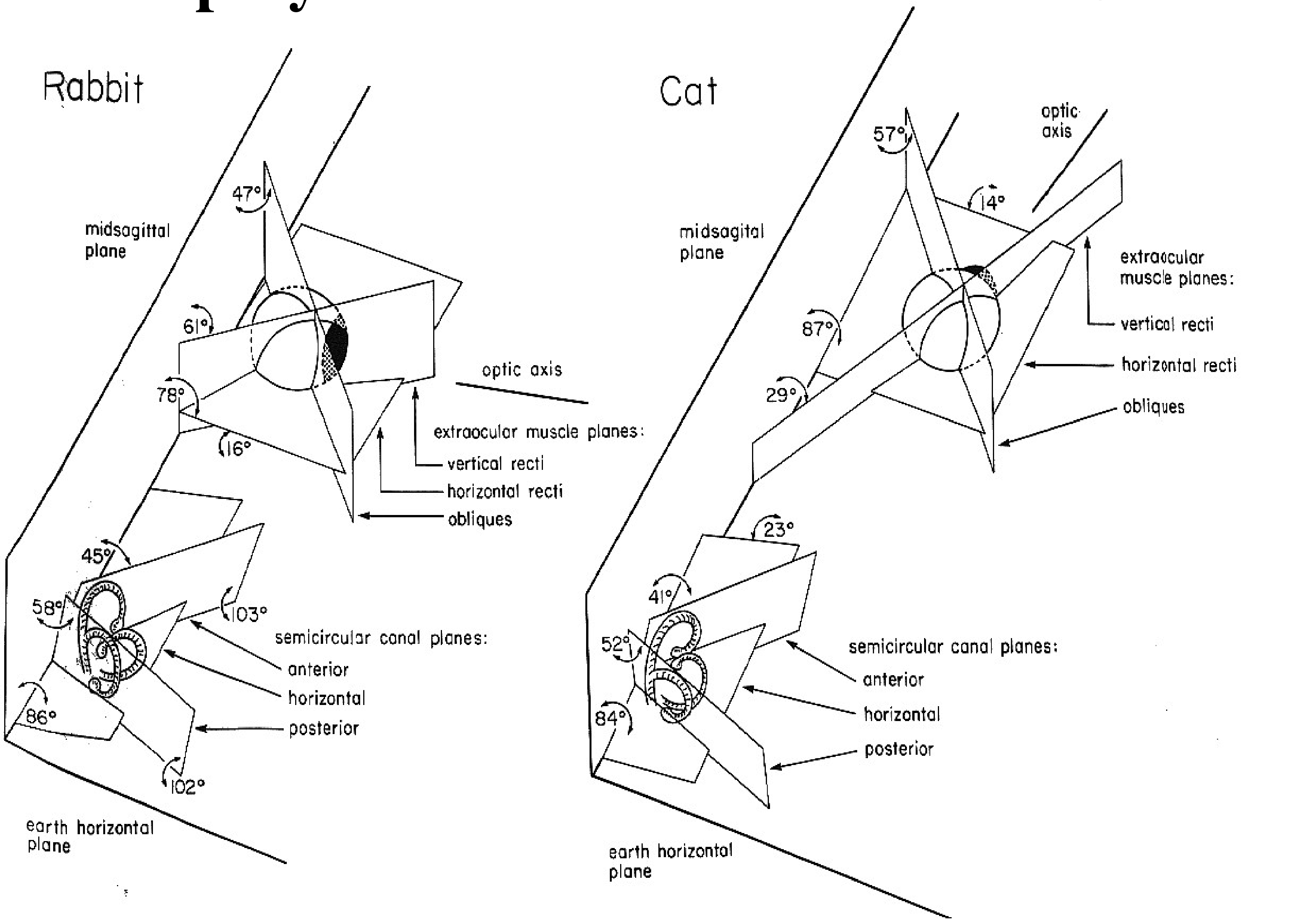
Benzene ring notation for primary and secondary muscle actions:



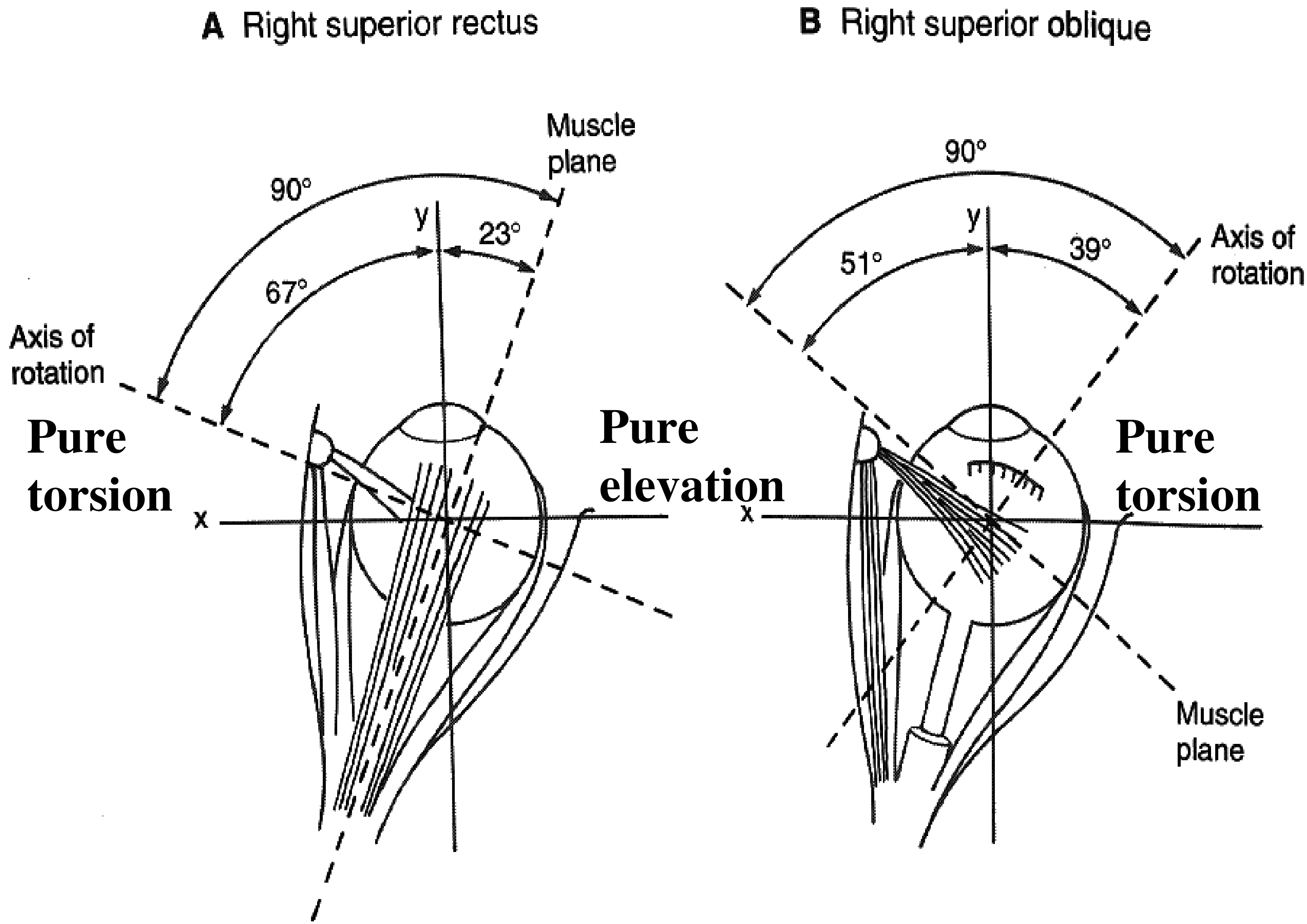
Three **Muscle Planes** predict actions of agonist-antagonist muscle pairs in different directions of gaze.



Muscle planes are parallel to the canal planes to simplify the neural control of the VOR.

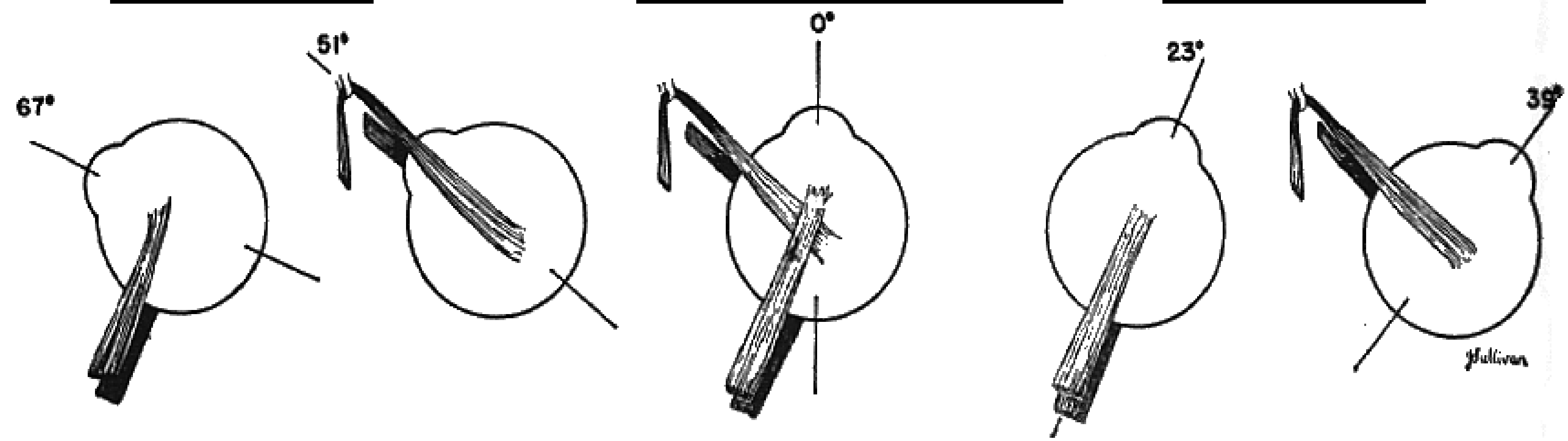


Visualize how contraction of a muscle in one of the three muscle planes would change the orientation of the line of sight.


A Right superior rectus
Muscle plane
90°
y
23°
67°
Axis of rotation
Pure torsion
Pure elevation
x
B Right superior oblique
90°
y
51°
39°
Axis of rotation
Pure torsion
x
Muscle plane

Muscle actions of the right-eye superior oblique and superior rectus during adduction and abduction.

Adduction **Primary Position** **Abduction**



SR intorts **SO depresses** **SR elevates** **SO intorts**

Field of Action-

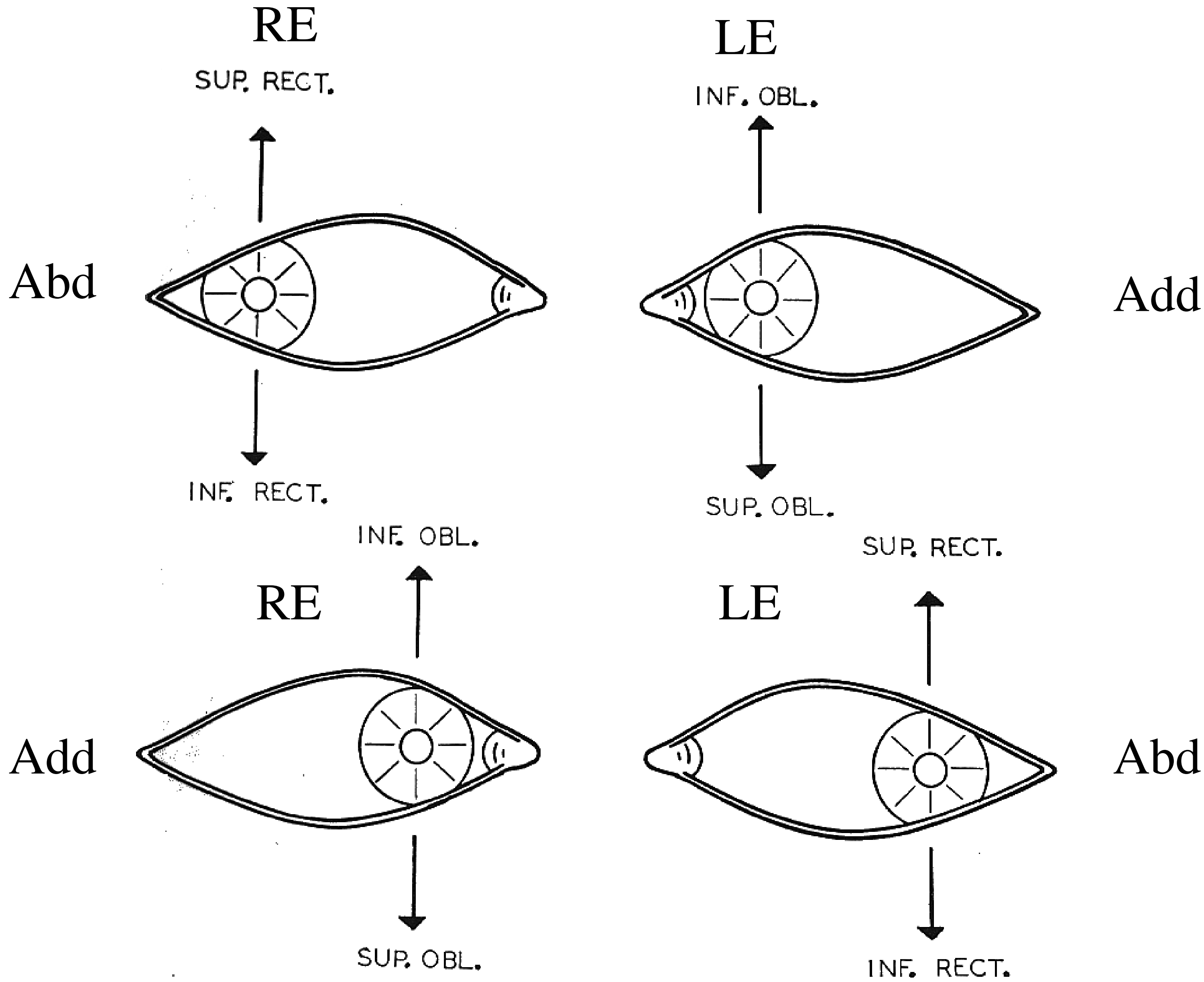
The horizontal direction of gaze (adduction or abduction) where the action of an EOM is pure elevation or depression.

i.e. Horizontal field of vertical action.

Horizontal fields (Add vs Abd) of vertical action for the obliques and vertical recti.

Rightward Version

Leftward Version

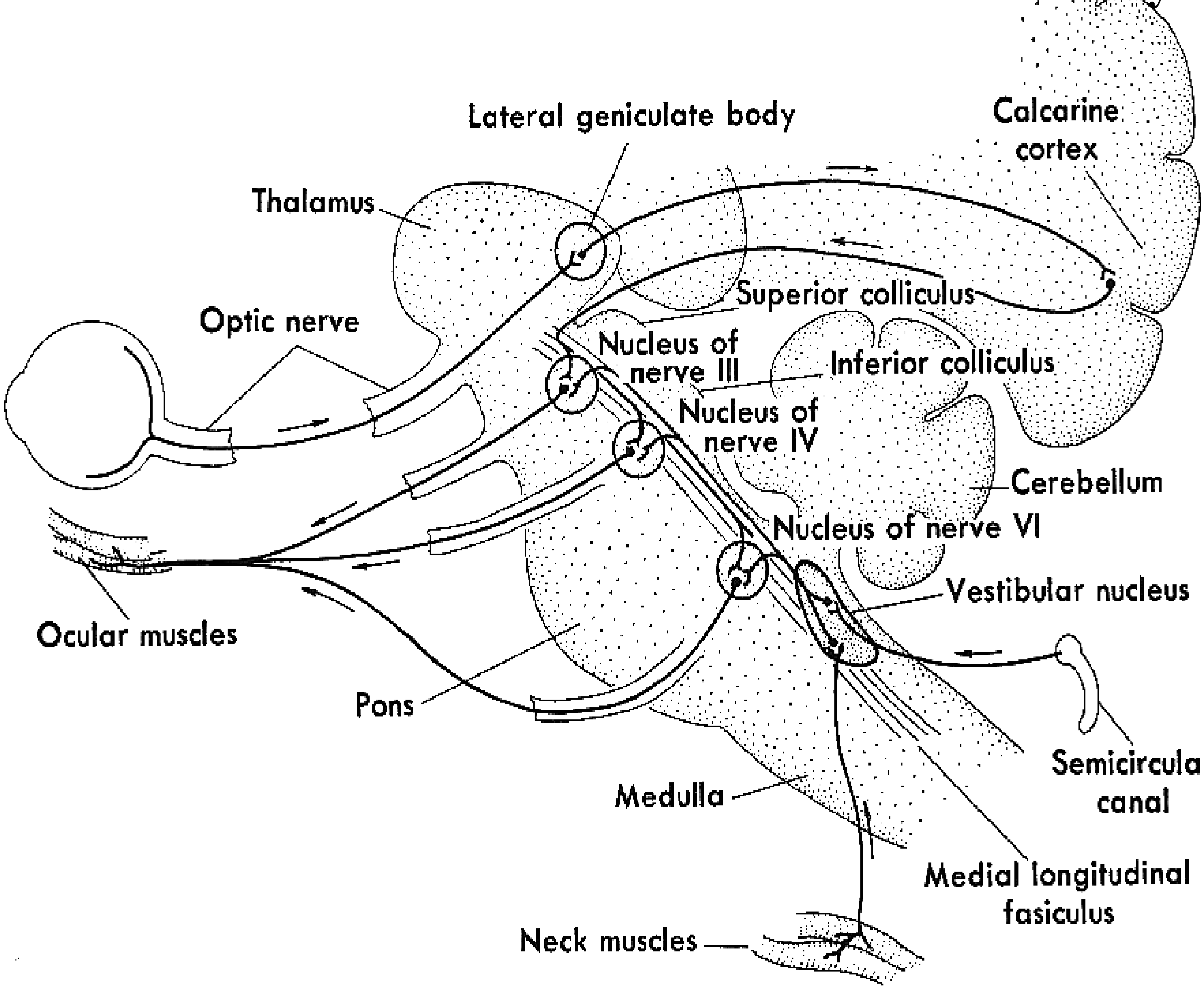


fMRI movie of IR activity

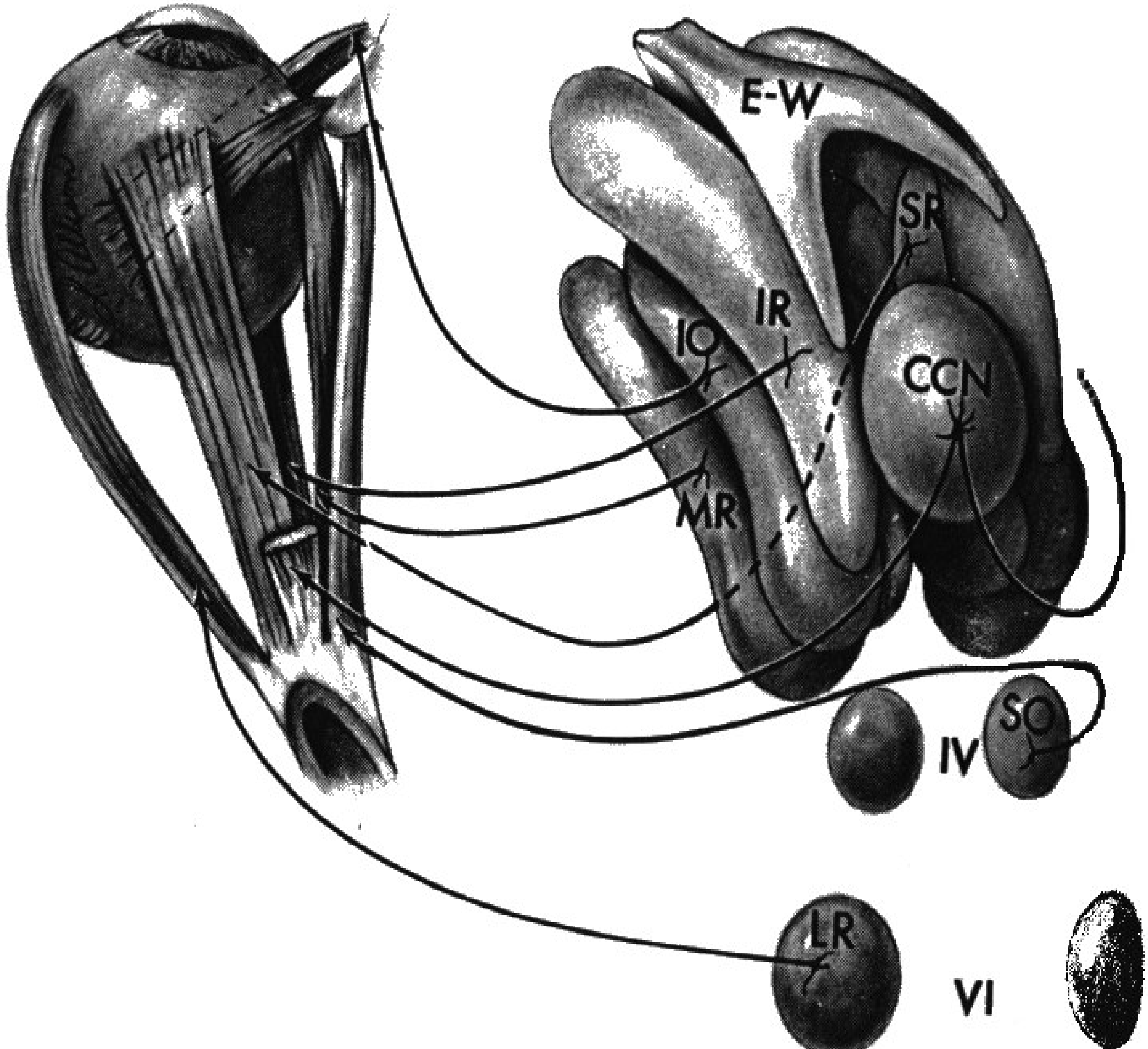
Muscle pulleys simplify the control of eye movements by moving the axis of muscle rotation with the eyes and this automatically produces Listing's predicted torsion. Vertical recti always move the eye vertically, even in strong abduction.

Surgical evidence: The expected benefits of the surgical treatment of LR palsy, by temporal translation of the insertion points of the two vertical recti (to produce temporal slide slip), is reduced by the Pulleys (D Robinson).

Brain stem sites of cranial nerves- Final Common Pathway



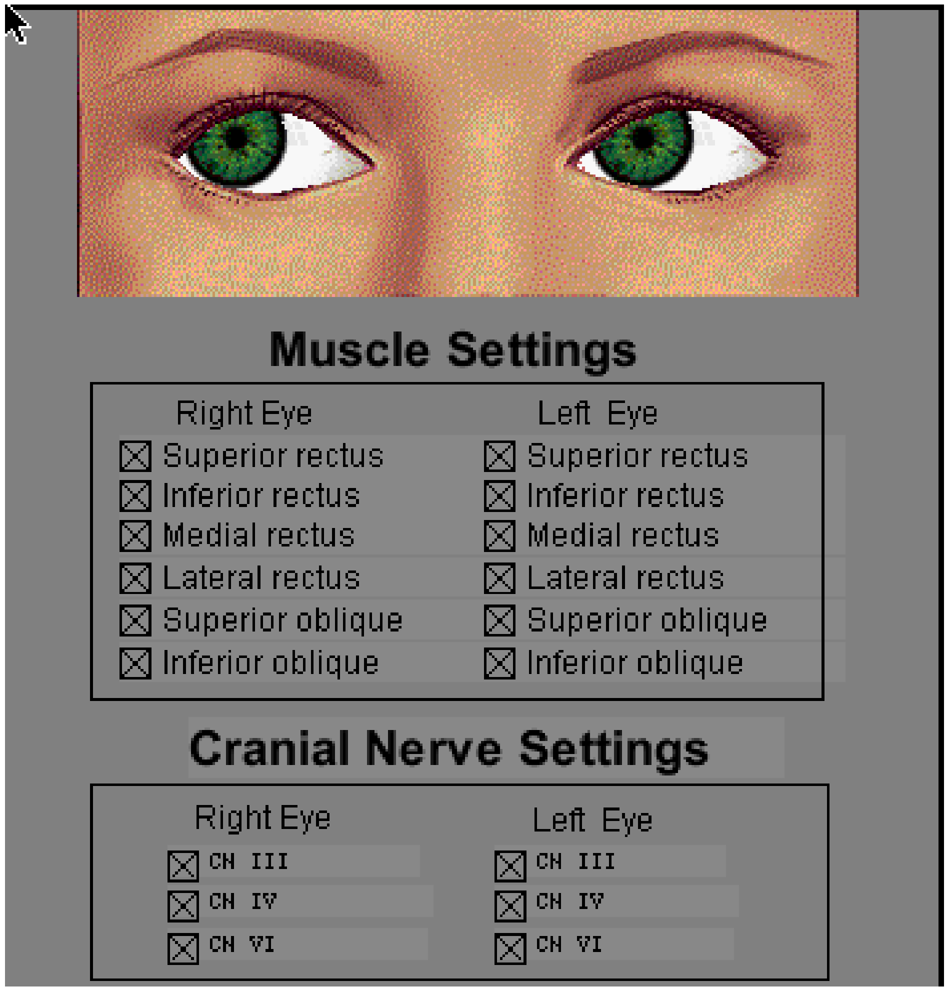
Oculomotor nucleus III innervates MR, IR, SR, IO



EOM action demo web site

http://cim.ucdavis.edu/eyes/version15/eyesim.html

Evaluation of non-concomitant Paresis or Paralysis



Anomalies of The Final Common Pathway-

Brain-stem motor nuclei of the cranial nerves (III, IV and VI).

Muscles and cranial nerves: LR_6 SO_4 All else controlled by III

Paresis: Partial loss of muscle function

Paralysis - Complete loss of muscle function

Palsy- Restricted movement in a given direction (premotor anomaly)

Lesions of cranial nerves cause paralysis and paresis

III- Ophthalmoplegia

IV- Trochlear Palsy (most commonly seen in optometry)

VI- Abducens or LR Palsy (longest course, most prone to injury)

Diagnostic Positions of Gaze based on Horizontal Fields of Vertical Action

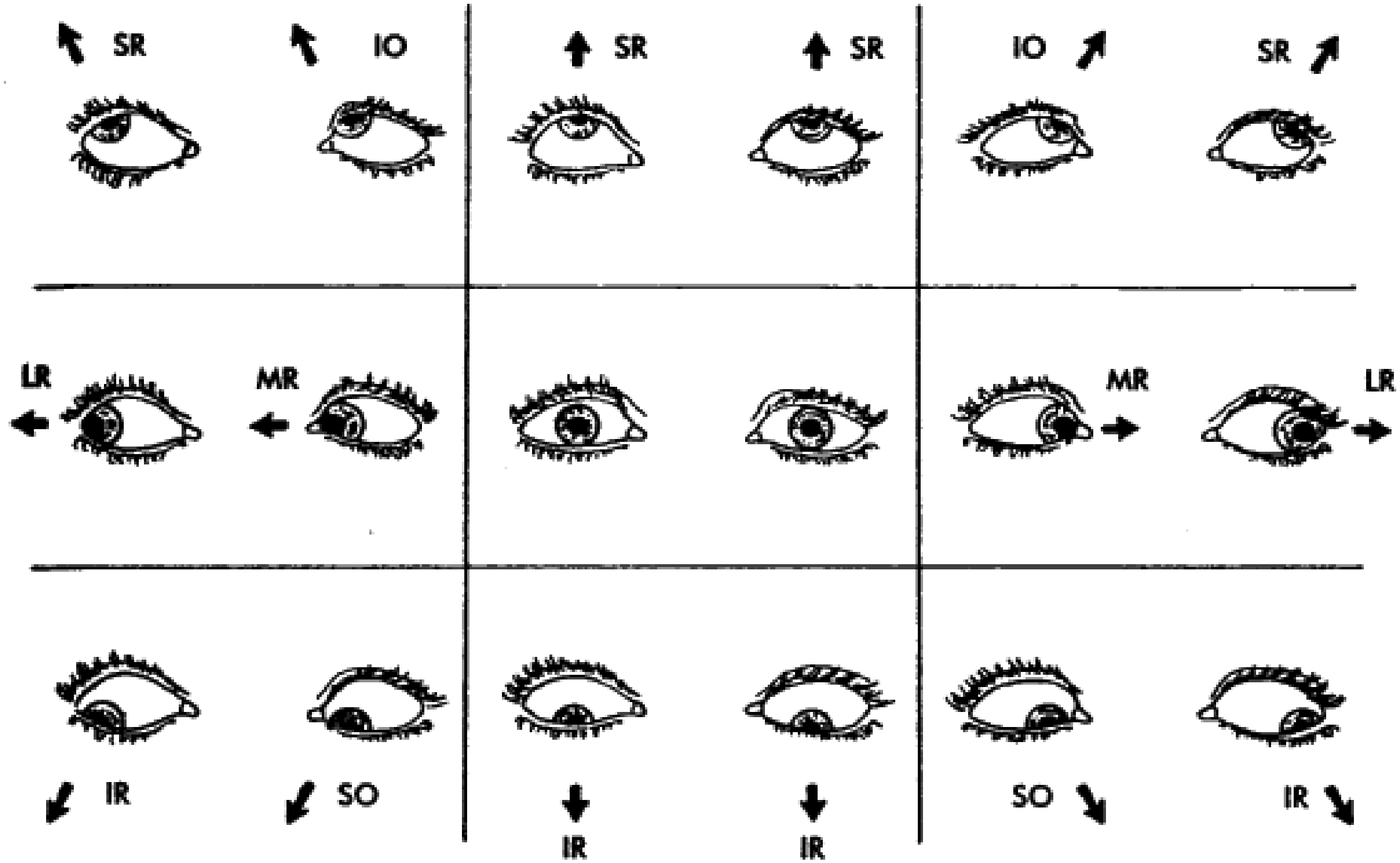
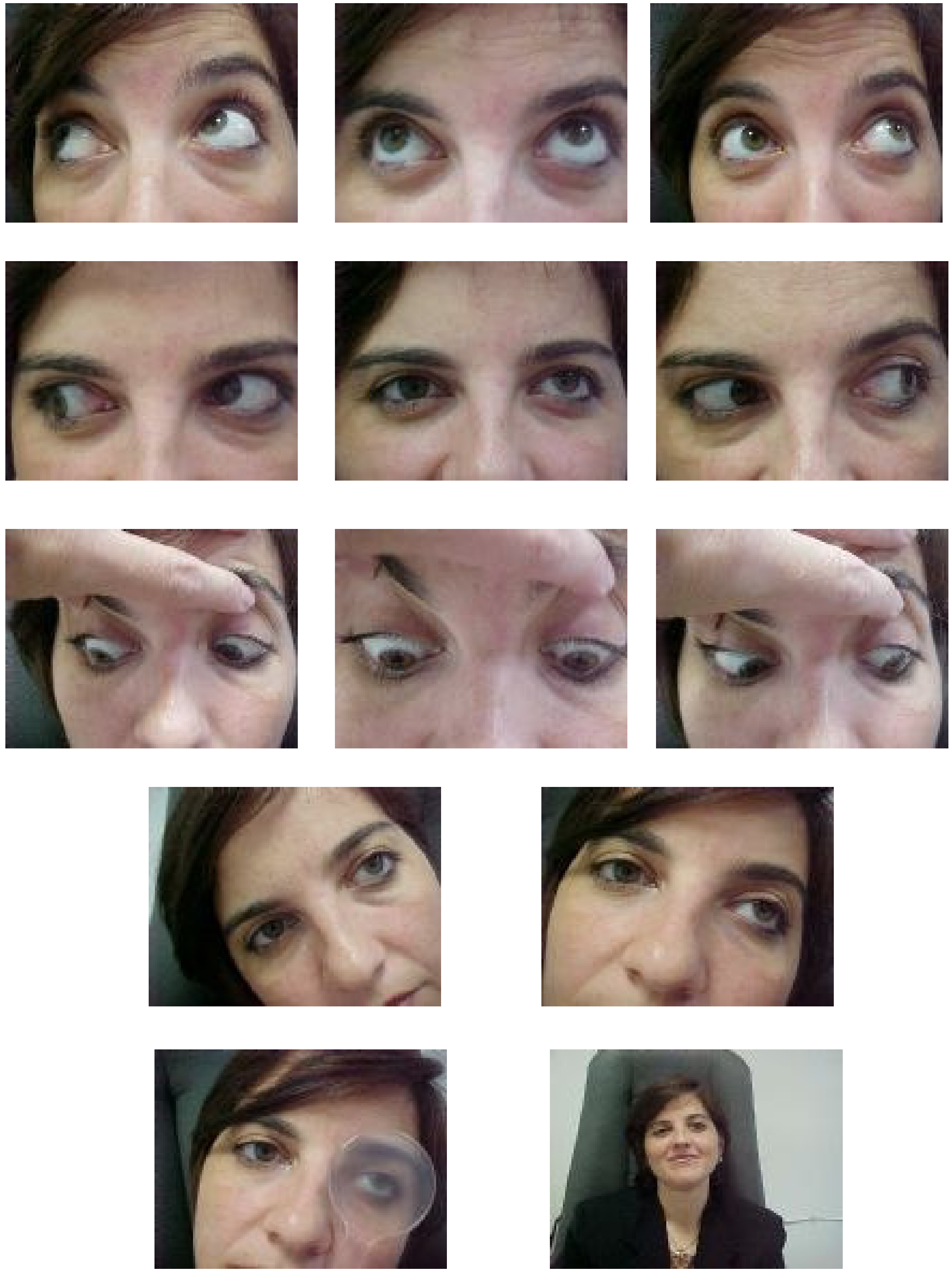


FIG. 1-5 The nine diagnostic positions of gaze. *SR,* superior rectus; *IO,* inferior oblique; *LR,* lateral rectus; *MR,* medial rectus; *IR,* inferior rectus; and *SO,* superior oblique.

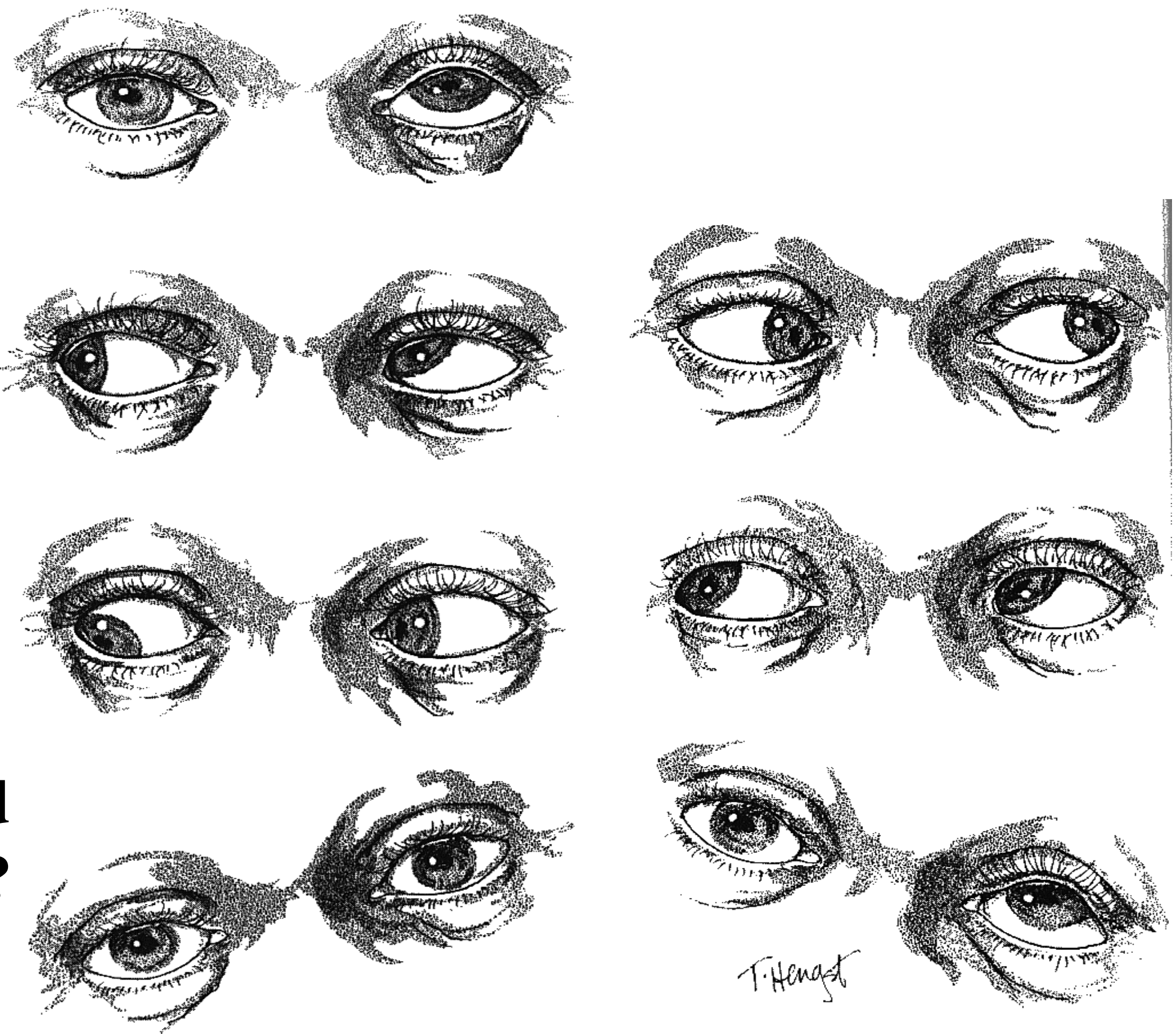


Parks 3 Step Test: SO palsy

Right or left eye Hypertropia?

Worse on left or right gaze?

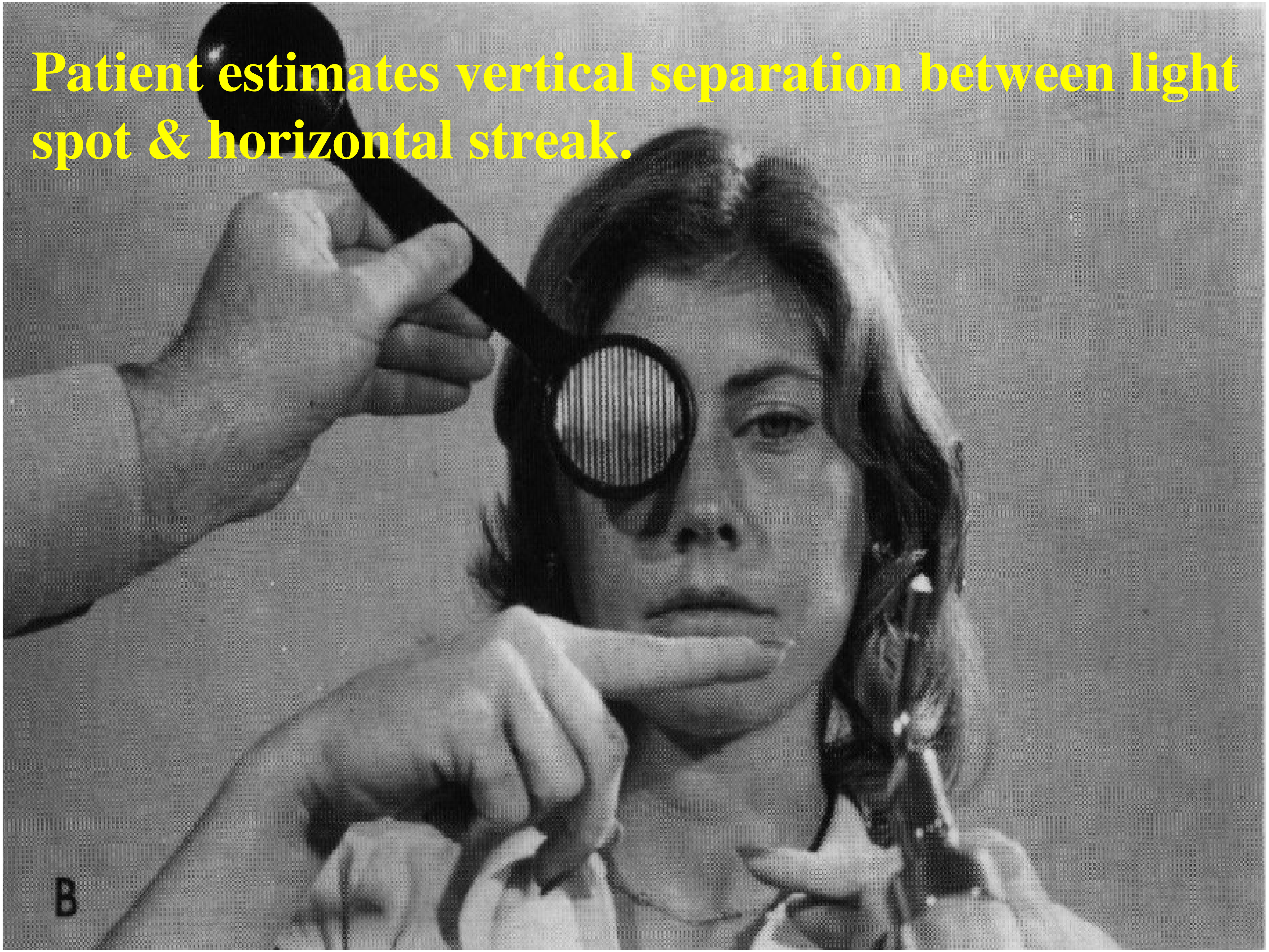
Worse with head Tilt left or right?



The Maddox Rod Test

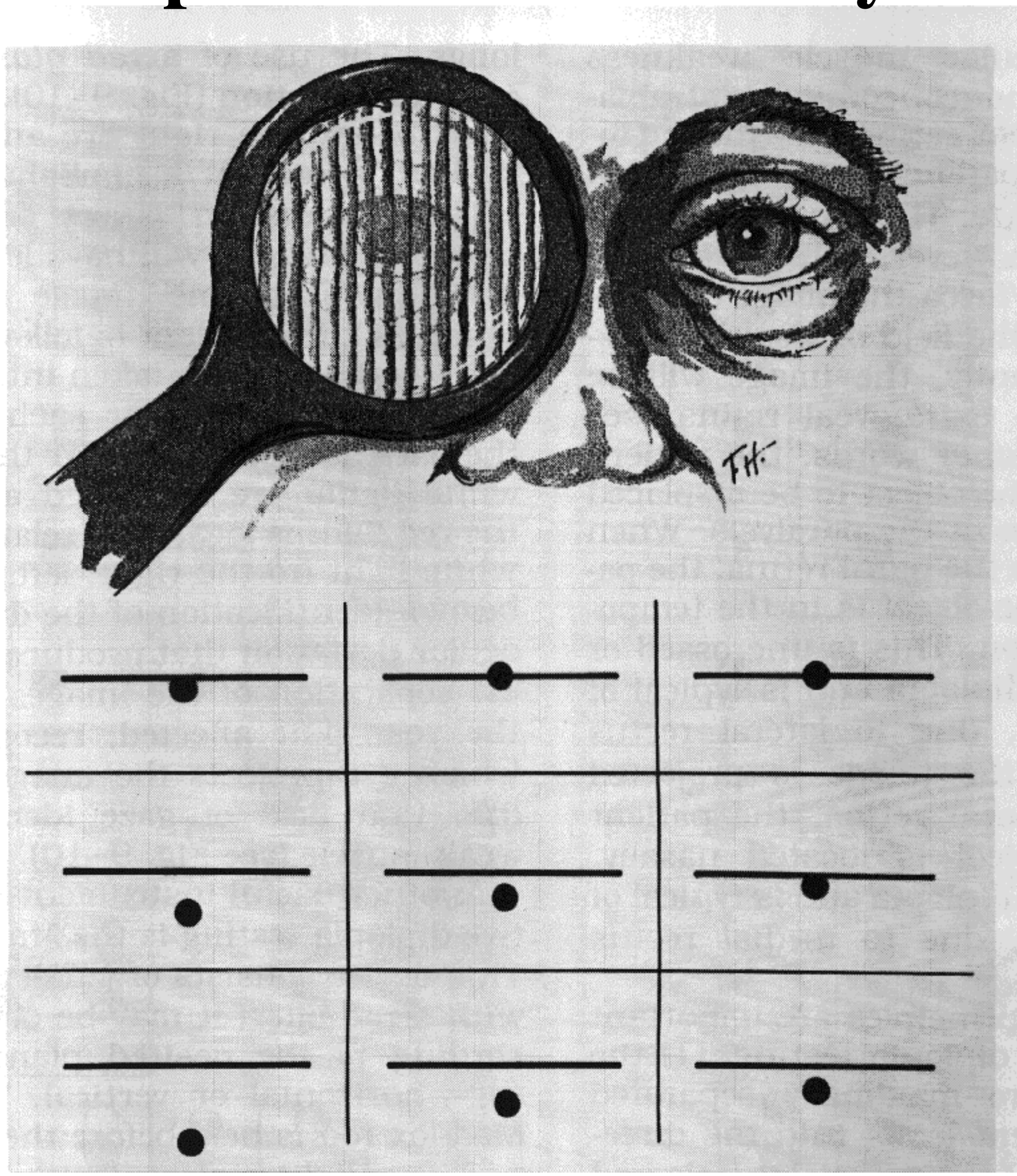

Maddox Rod (vertical streak with horizontal rods).


Patient estimates horizontal separation between light spot and vertical streak
A


Patient estimates vertical separation between light spot & horizontal streak.
B

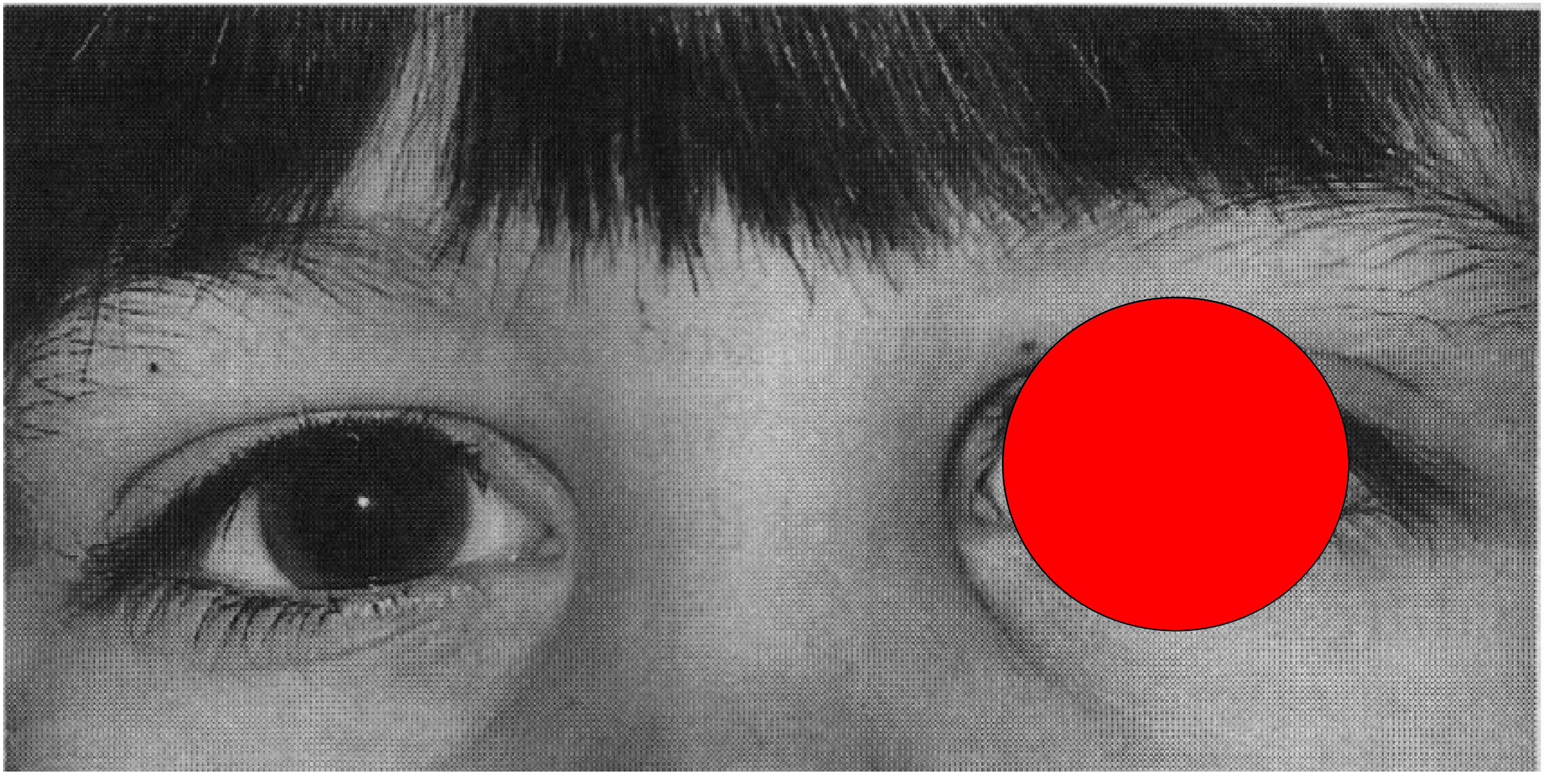
Patient fixates the right eye red horizontal streak & notes vertical separation from left eye white spot.

Patient's right

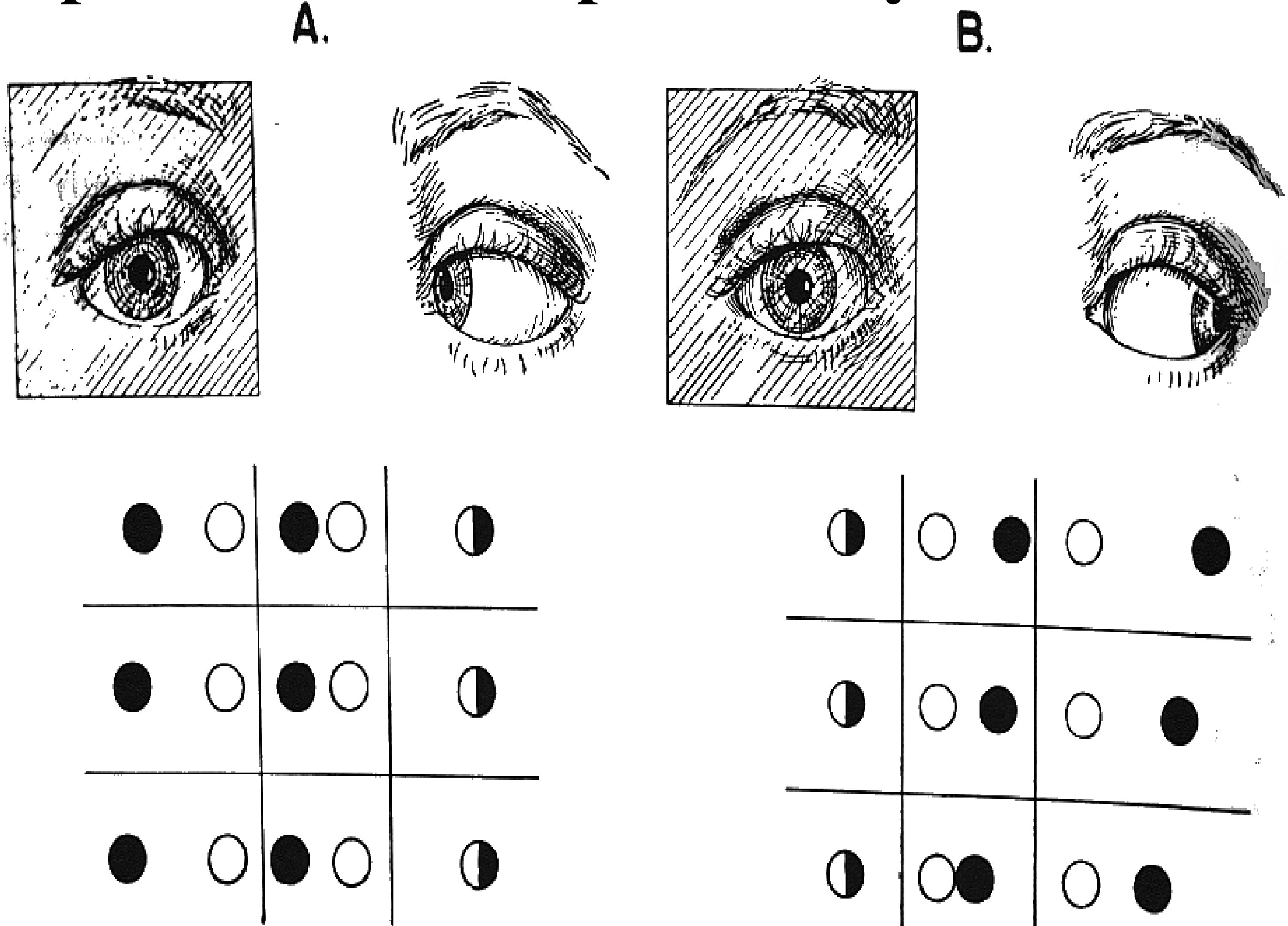


Patients left

The Red Lens Test



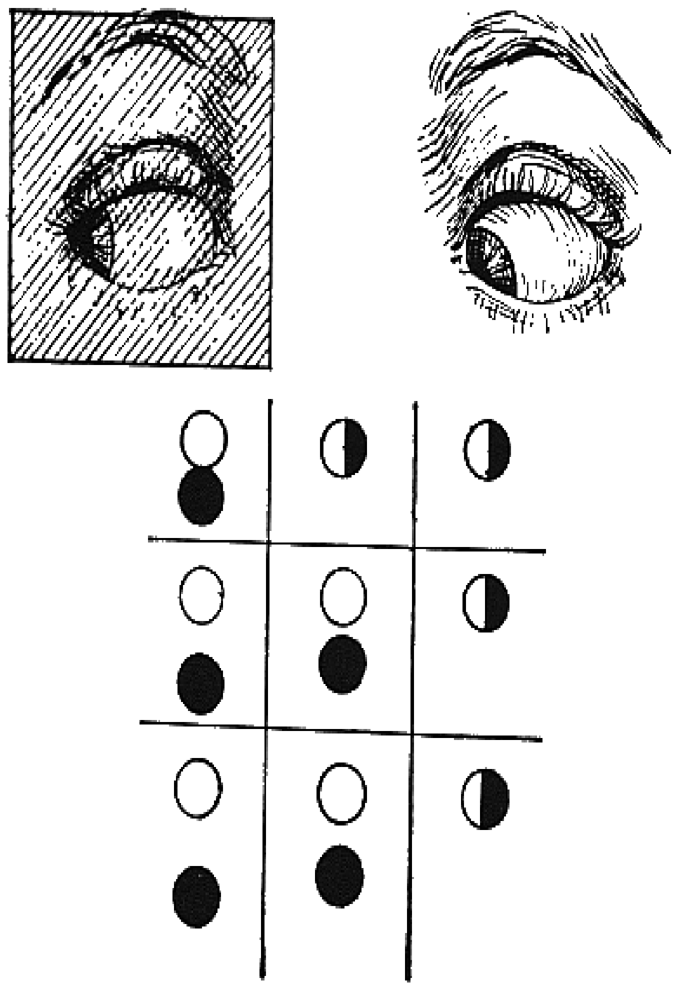
Patient indicates the separation between the fixated white spot and the red spot seen by the deviating eye.



LR palsy

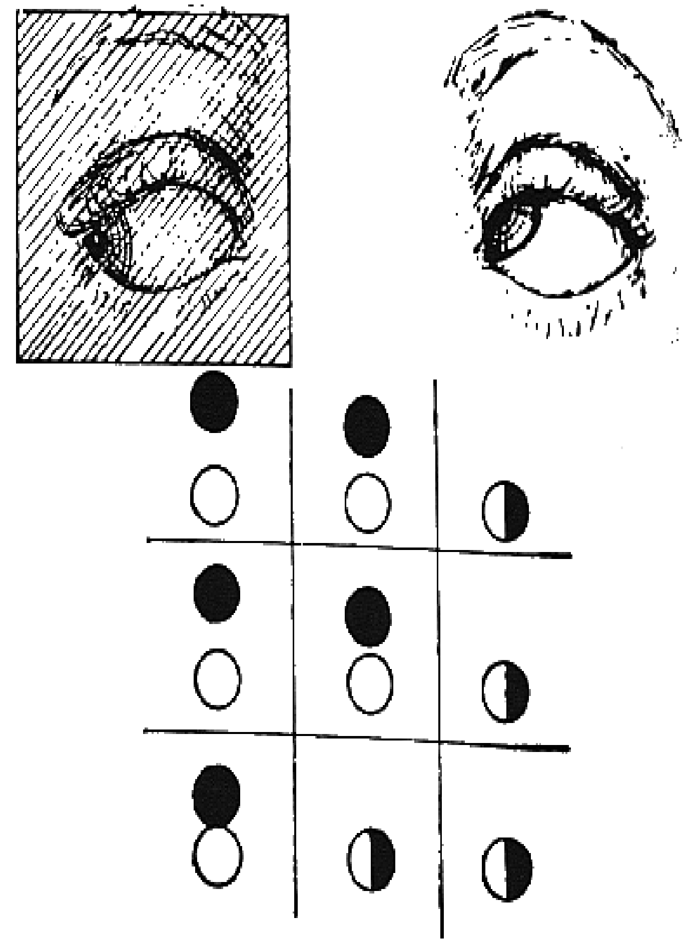
MR palsy

C.



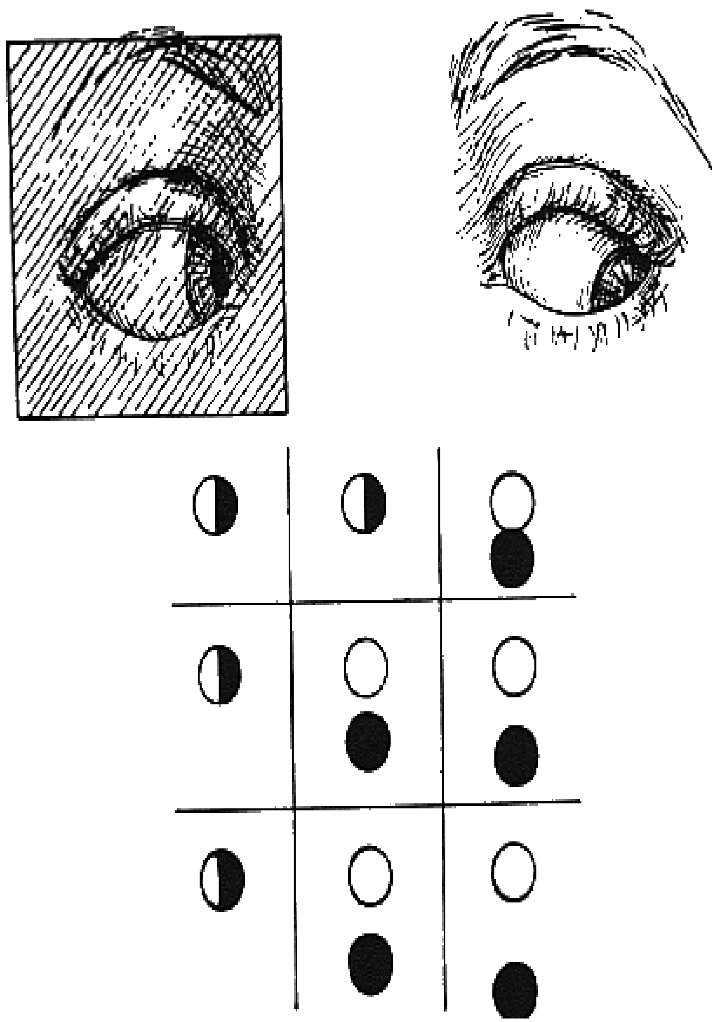
IR Palsy

D.



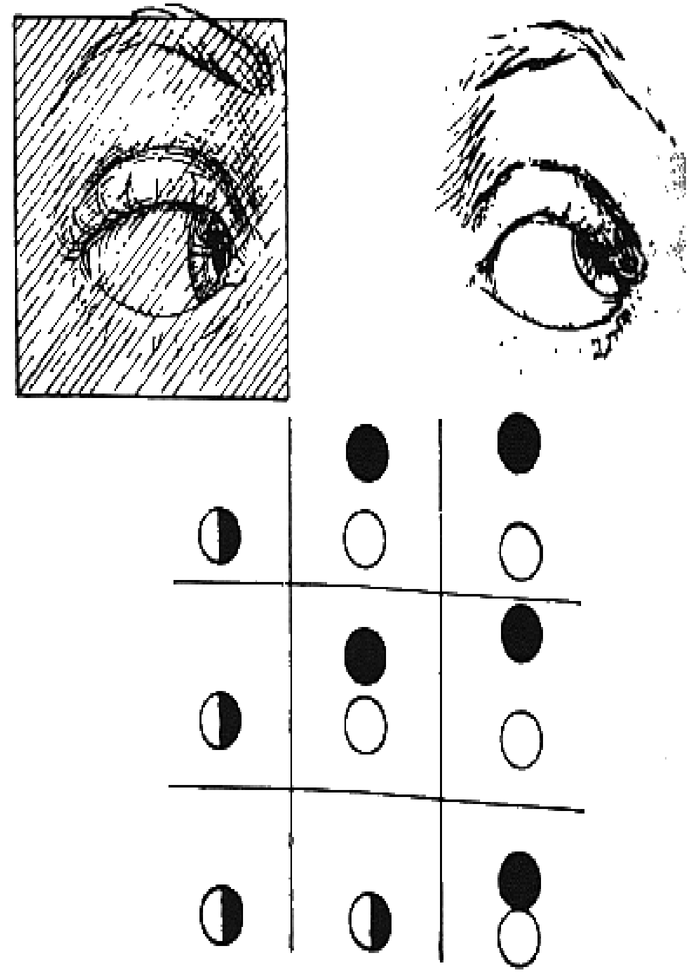
SR Palsy

E.



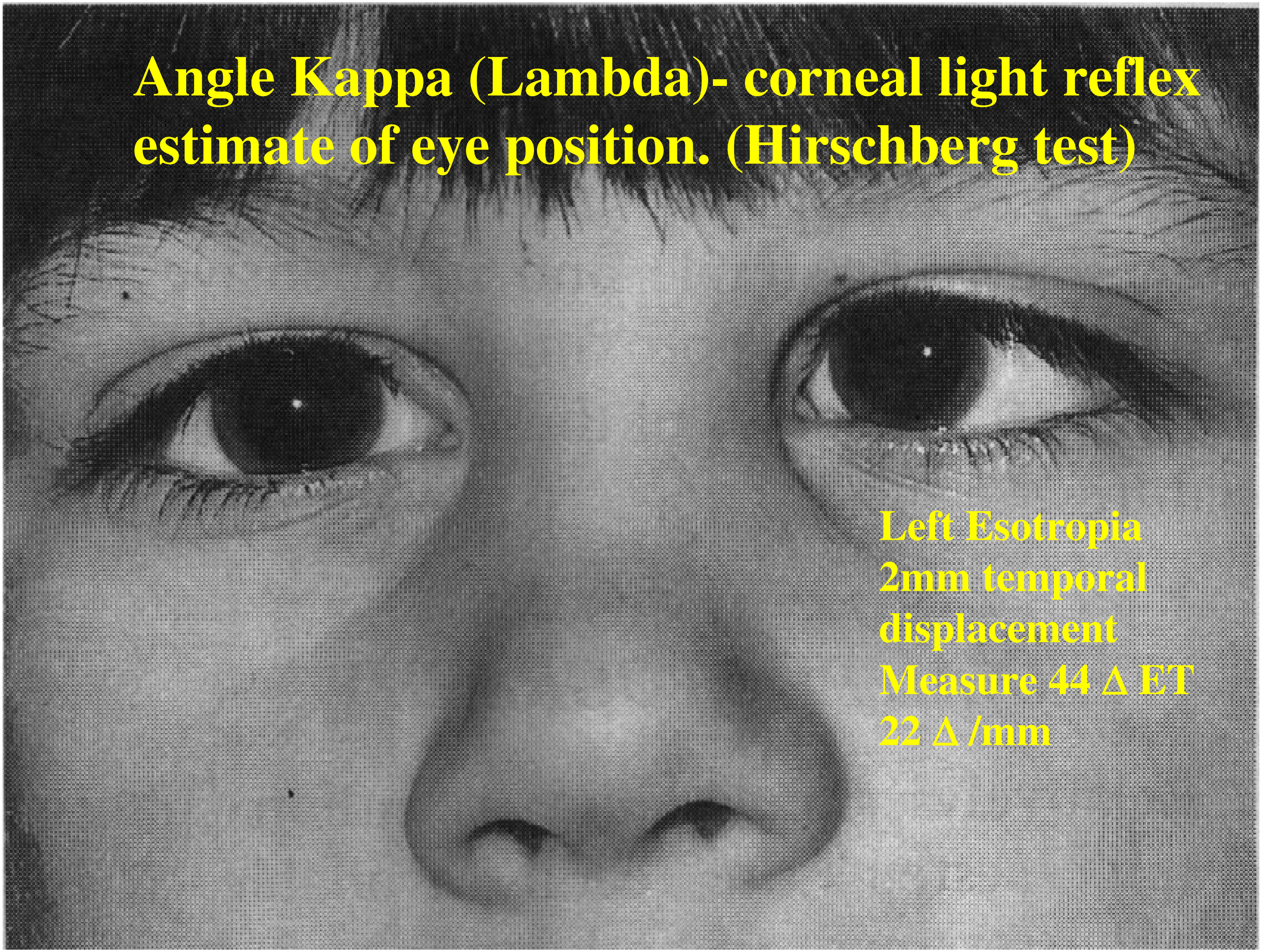
SO Palsy

F.

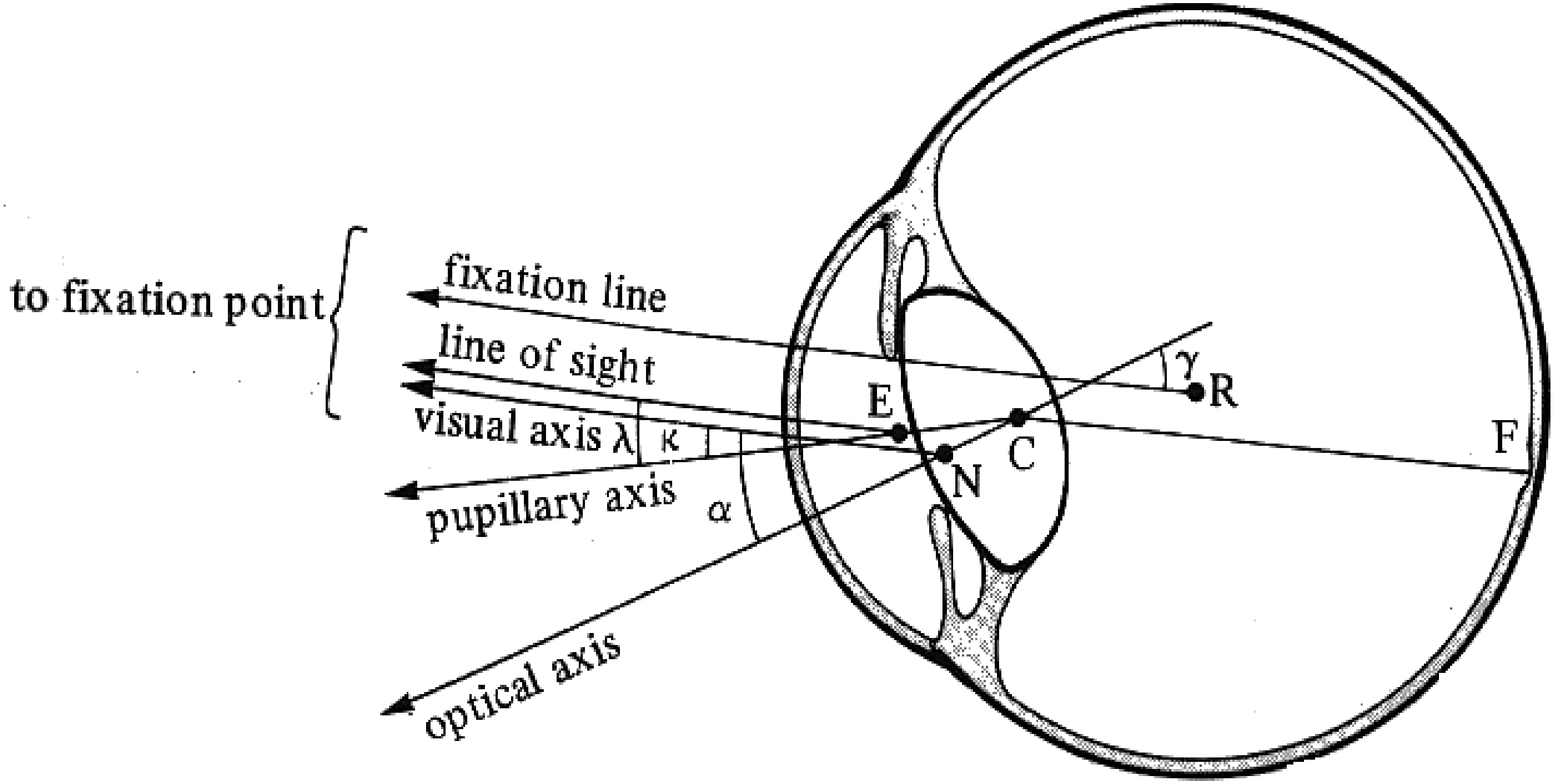


IO Palsy

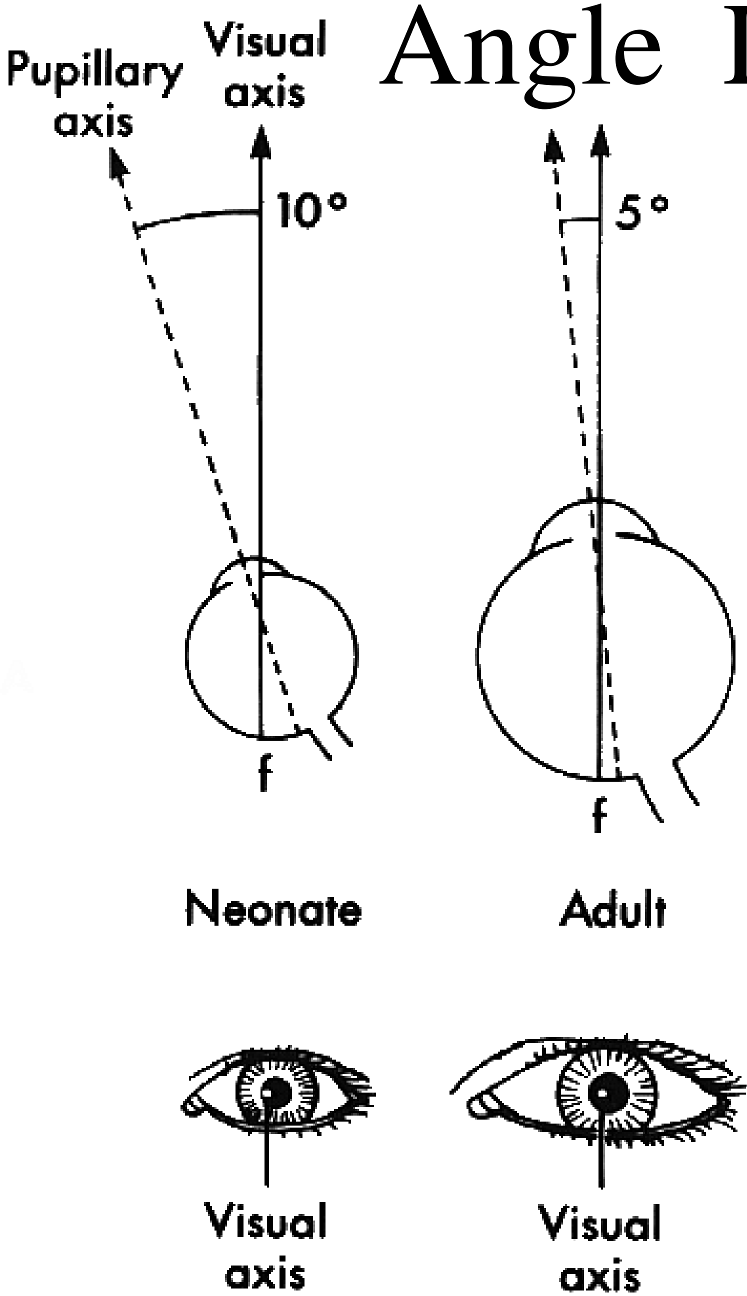
Angle Kappa (Lambda) used in the Hirschberg test for eye alignment.


Angle Kappa (Lambda)- corneal light reflex estimate of eye position. (Hirschberg test)
Left Esotropia
2mm temporal displacement
Measure 44 Δ ET
22 Δ /mm

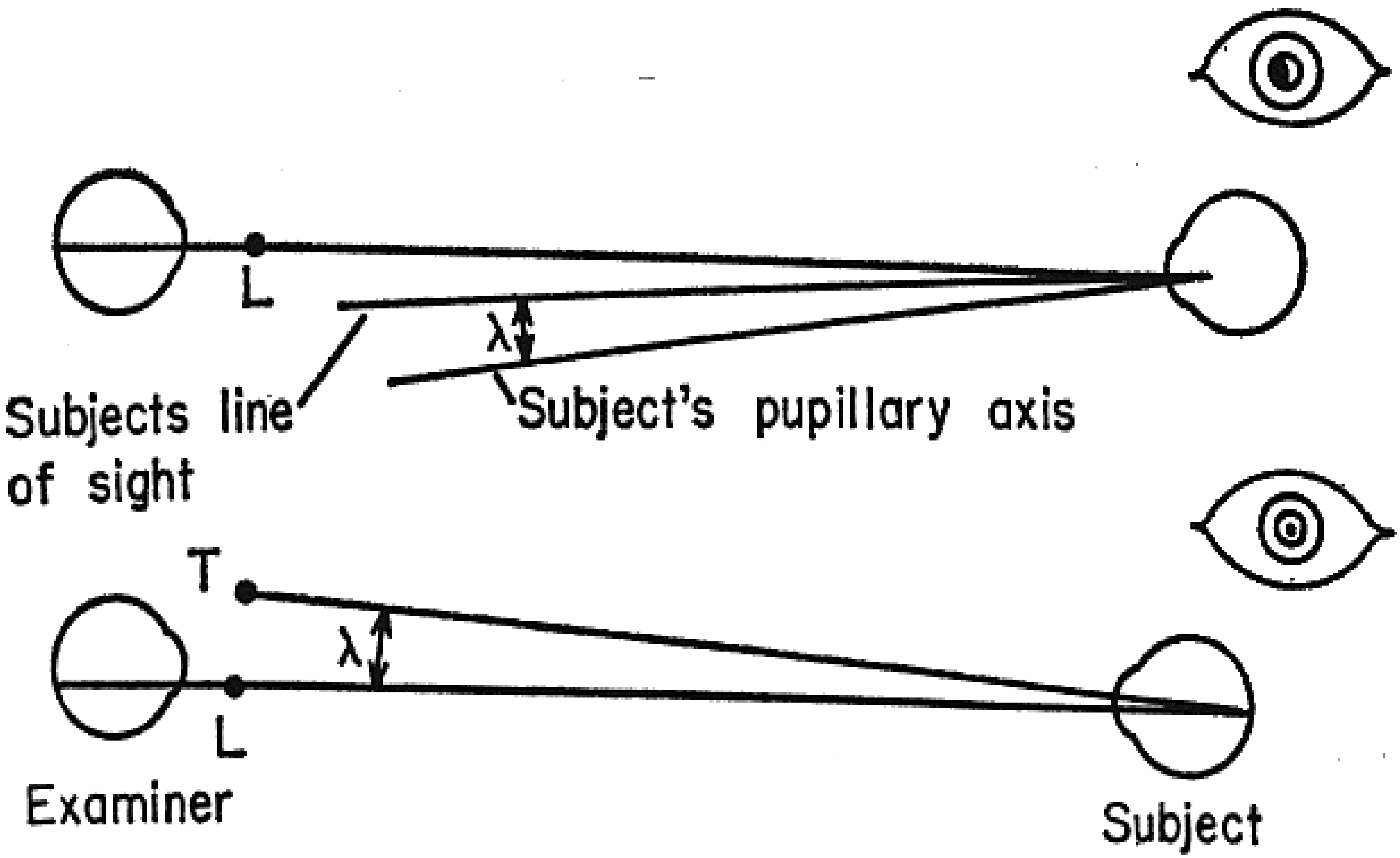
Visual Angles



Angle Lambda (Kappa)

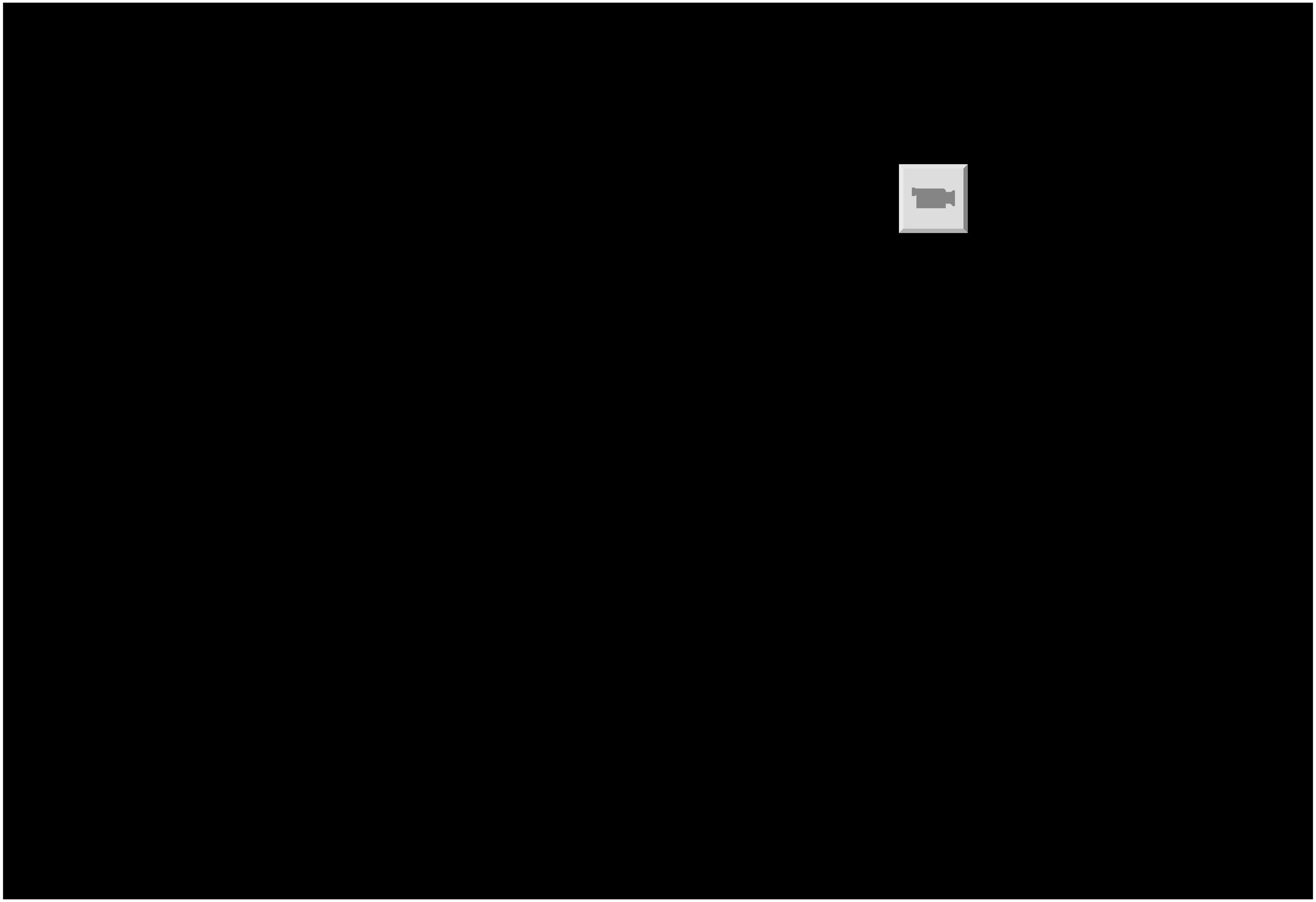


Clinically angle Lambda is called angle Kappa.

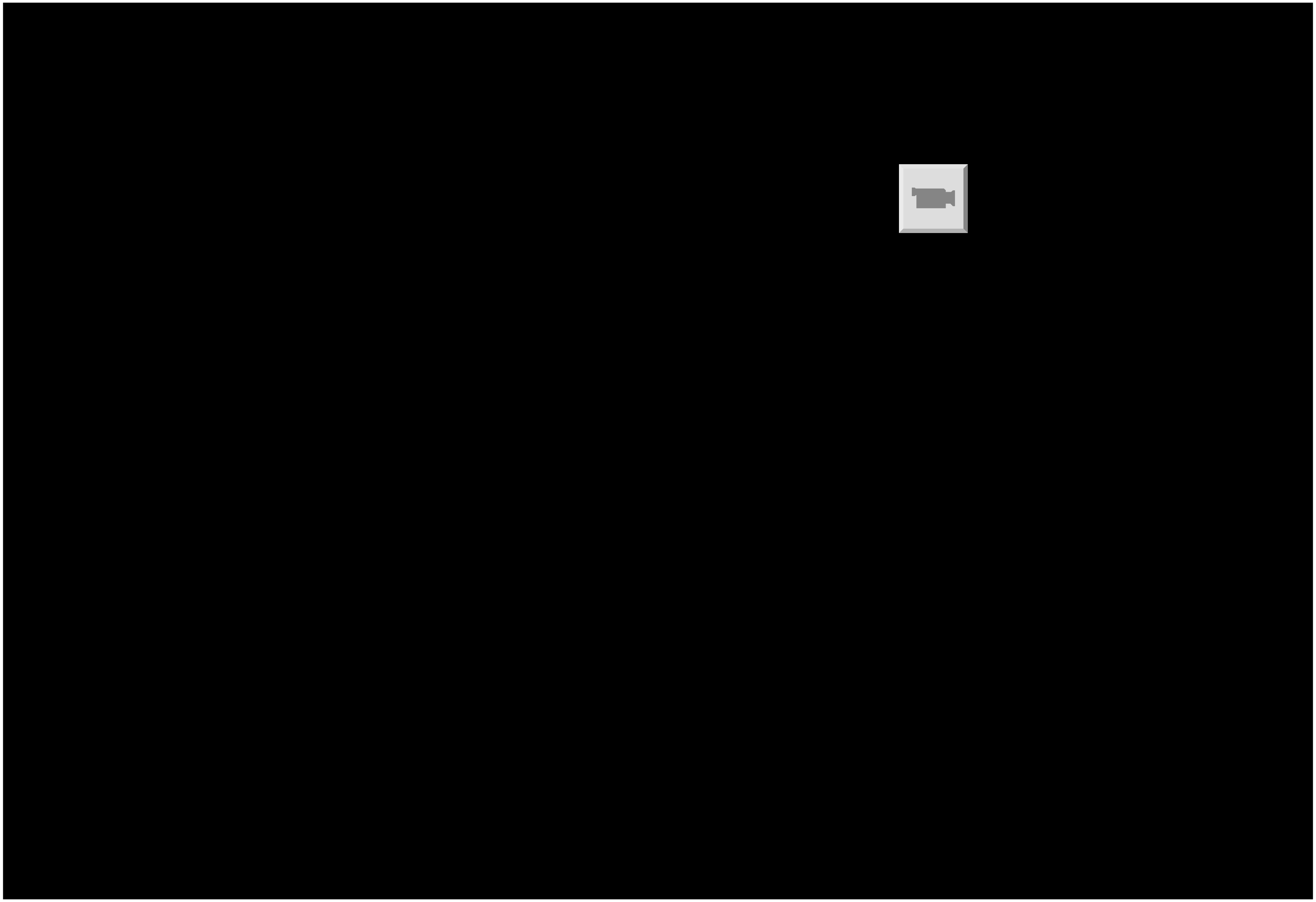


Method of measurement of the angle lambda.

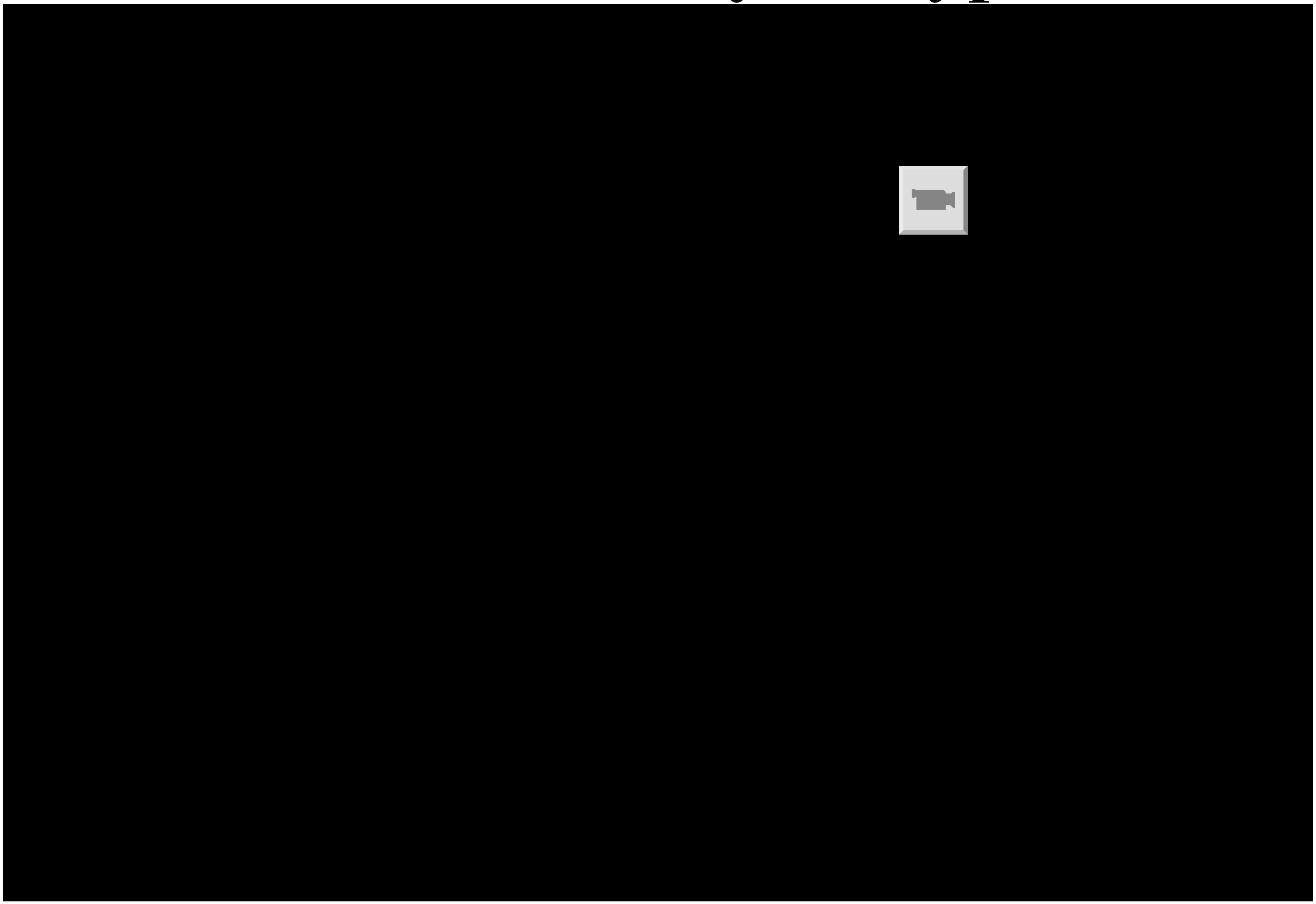
Cranial Nerve III Unilat CT, Alt XT



Cranial Nerve III- Alt CT, Alt XT

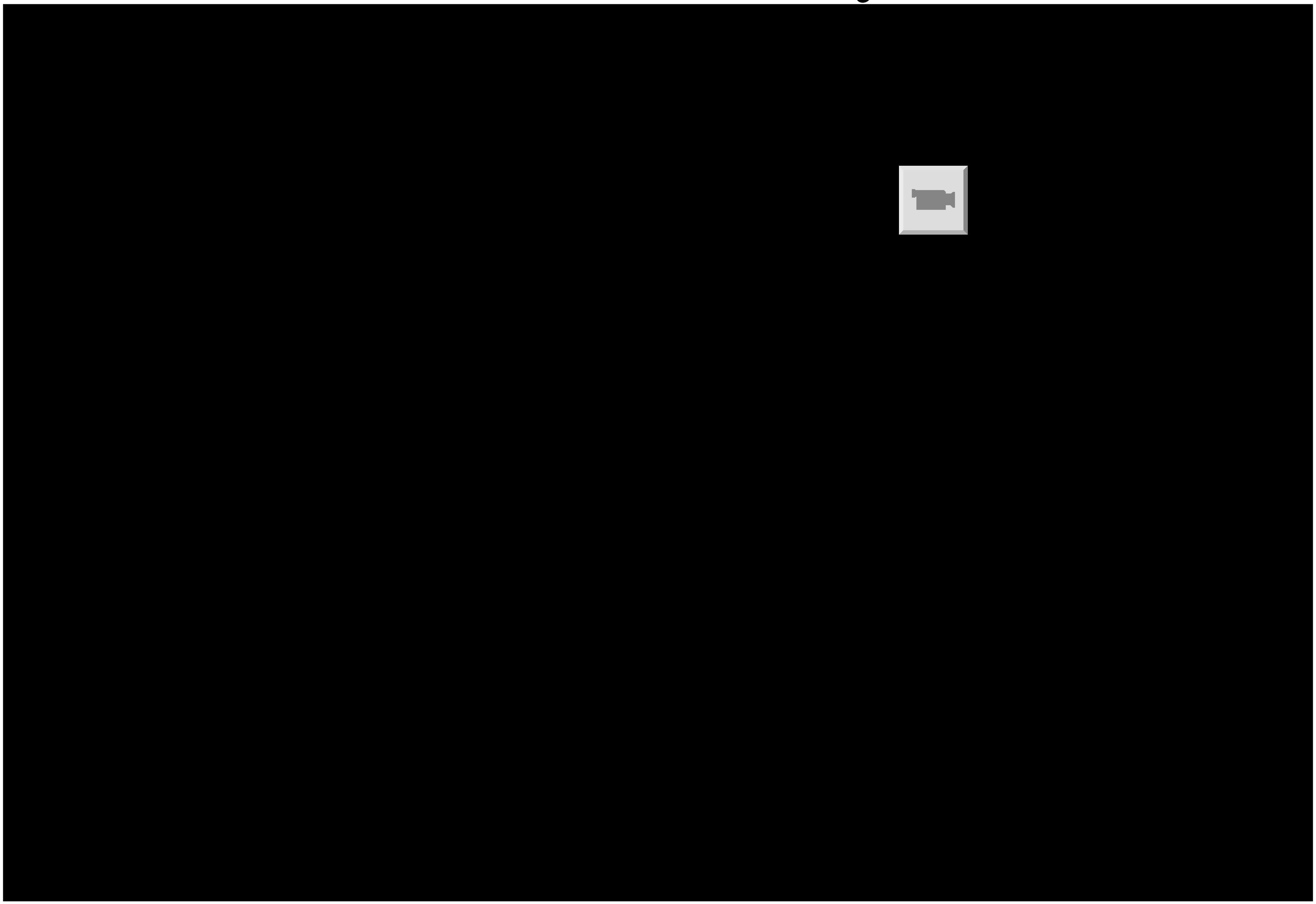


Trochlear Palsy, L hyper



Abducens Palsy, RLR paralysis

Duanes Retraction Syndrome

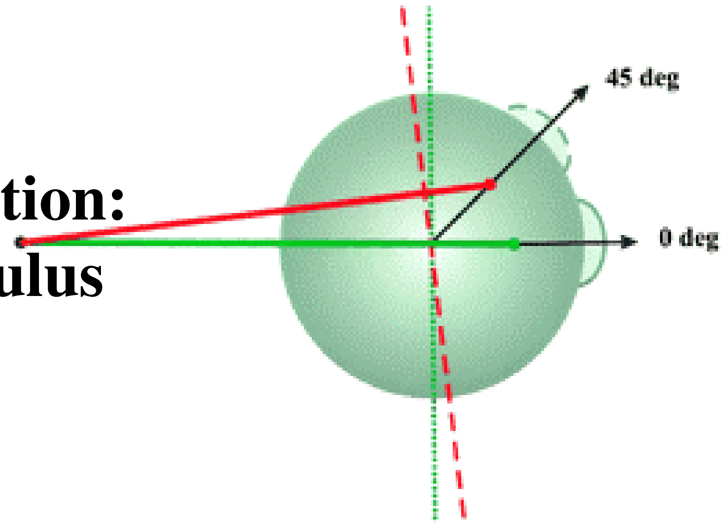


False Assumption: Muscle plane analysis assumes origin of muscles is at the back of the Orbit (annulus of Zinn). This predicts the that muscles don't move in the orbit (muscle slide slip) as suggested in the muscle plane illustration.

New Discovery: The real functional origin of the muscle is near the equator of the eye, at the muscle pulley. This origin causes the muscle to rotate with the eye and reduces the amount of slide slip.

A

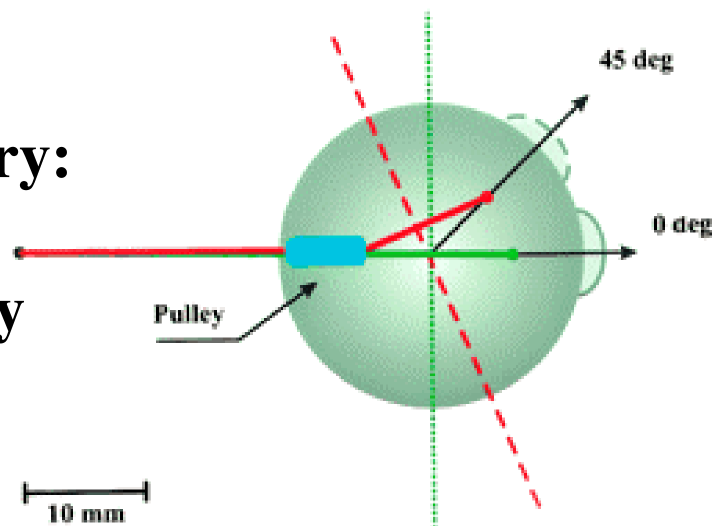
False Assumption: Origin at annulus of Zinn



Axis of rotation stays nearly fixed and muscle side-slips across the orbit.

B

New Discovery: Origin at Muscle Pulley



Axis of rotation moves with the eye and the muscle doesn’t side-slip across the orbit.

Muscle Pulleys- see page 791, chapter 34, Adler's

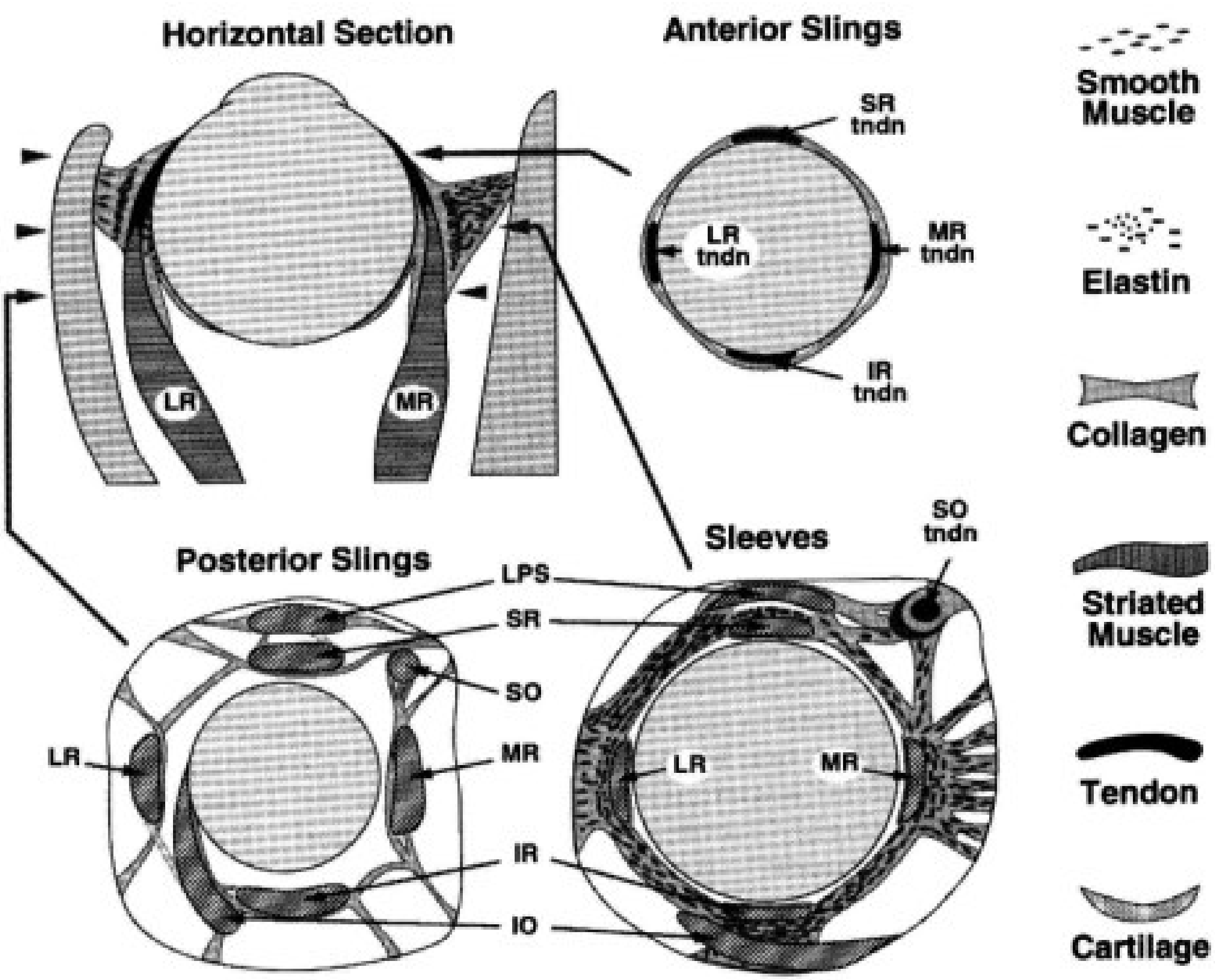
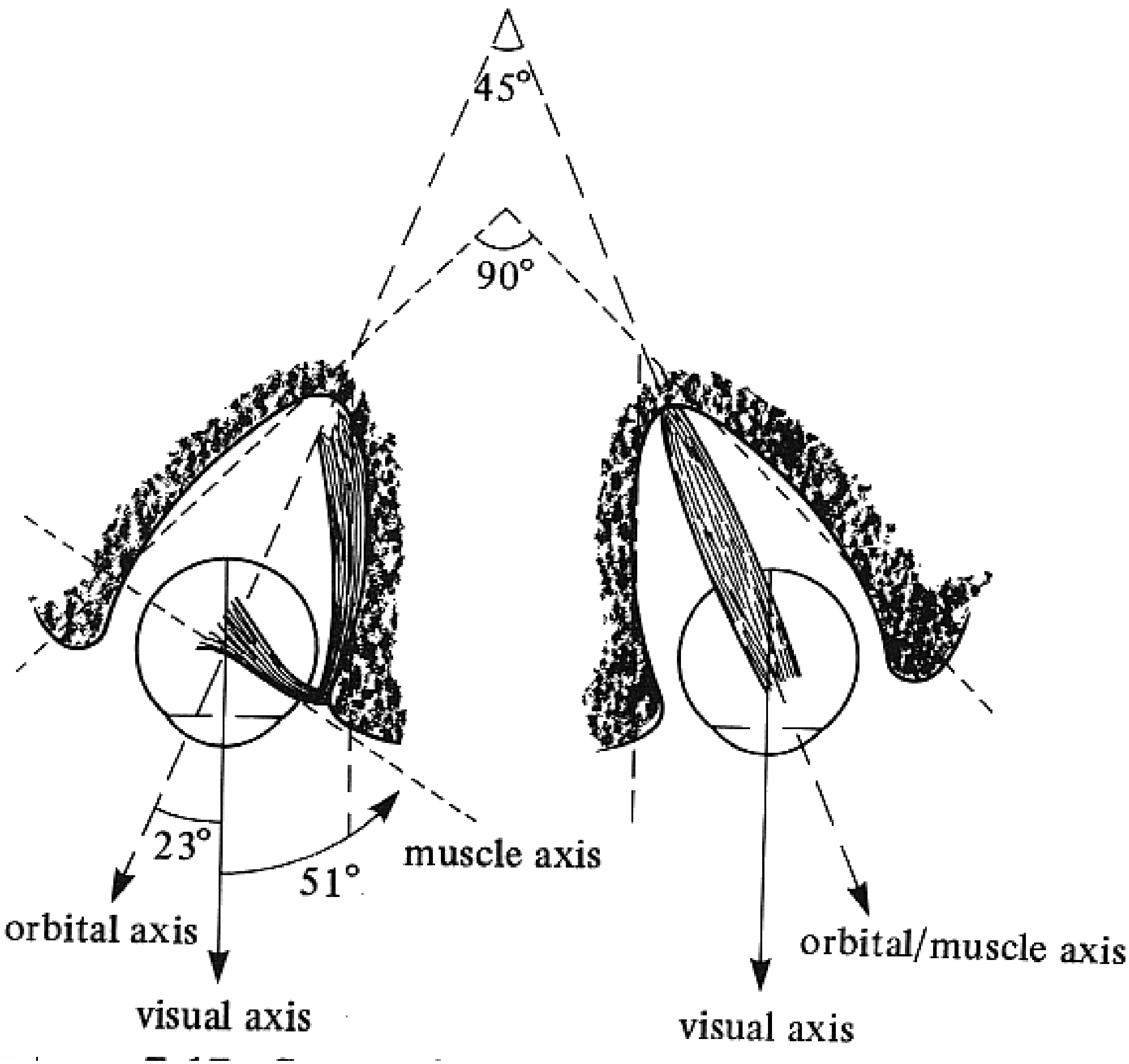
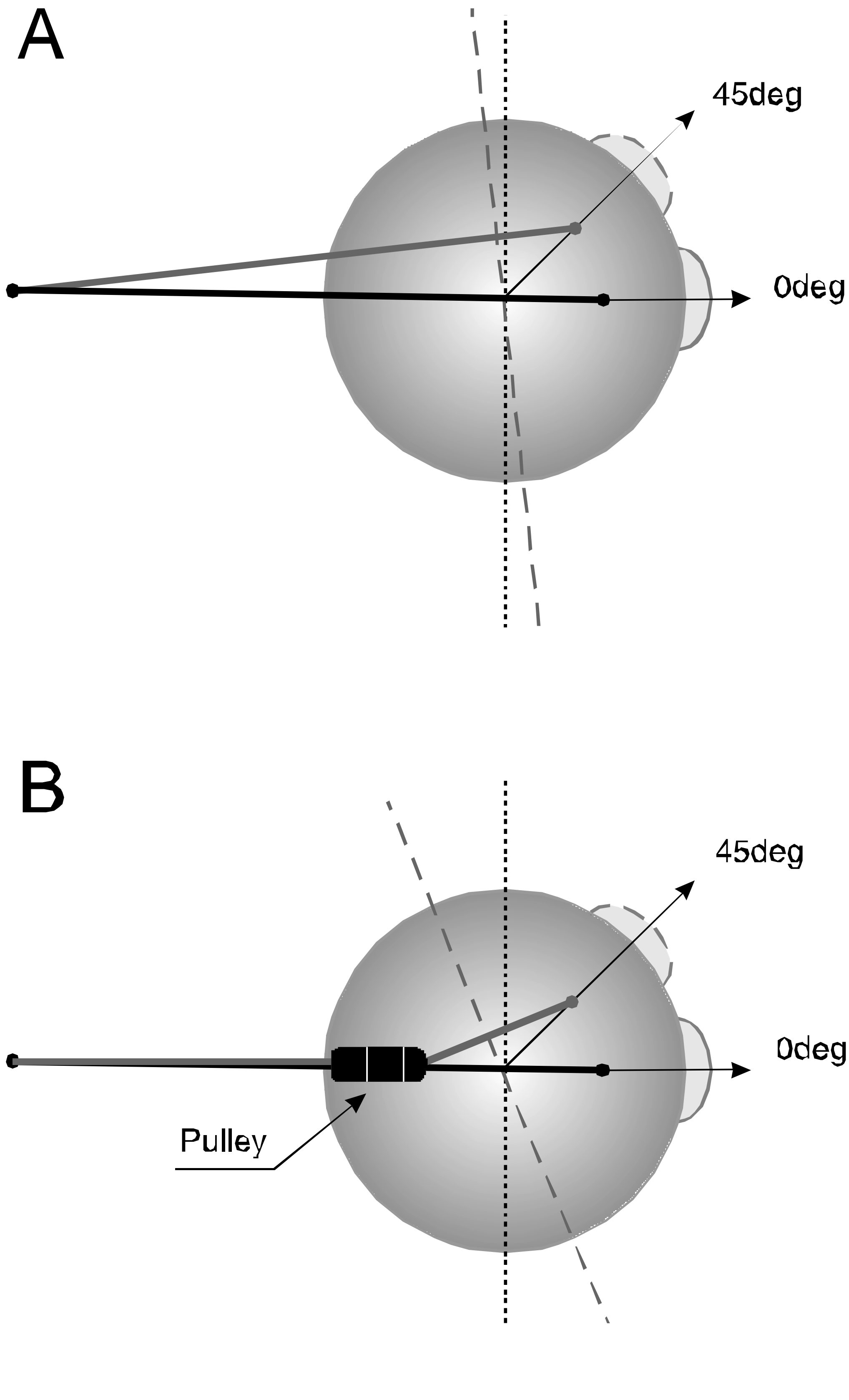
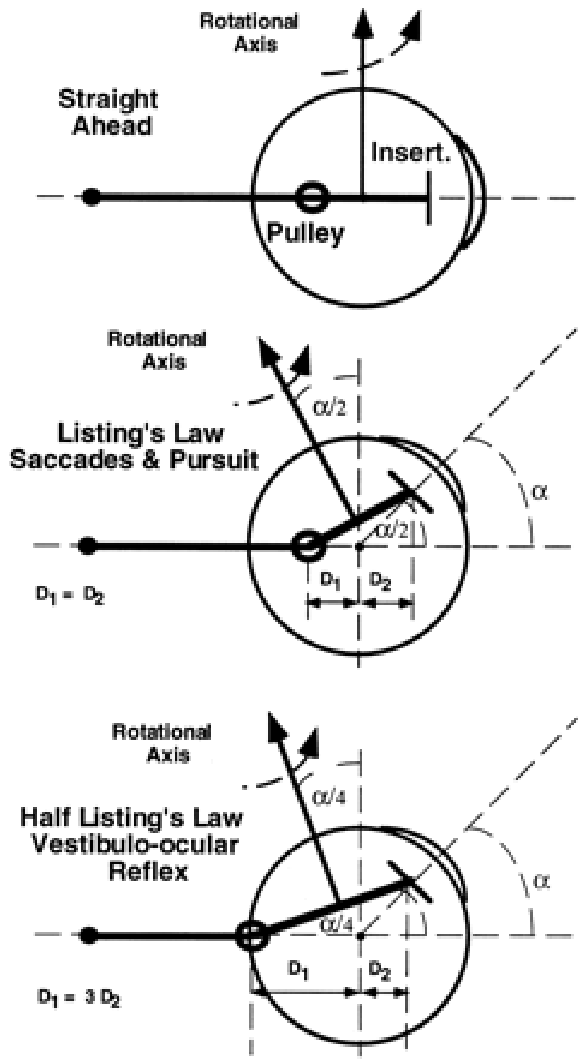


Figure 9–1. Schematic representation of orbital connective tissues. IR, inferior rectus; LPS, levator palpebrae superioris; LR, lateral rectus; M, medial rectus; SO, superior oblique; SR, superior rectus; tndn: tendon. The three coronal views correspond to the levels indicated by arrows in the horizontal section. In the horizontal section, note the attachment of the globe to the orbit by the anterior part of Tenon's capsule (collagen and elastin) through which the extraocular muscles pass in sleeves, which serve as pulleys. (Courtesy of Joel M. Miller and Joseph L. Demer.)

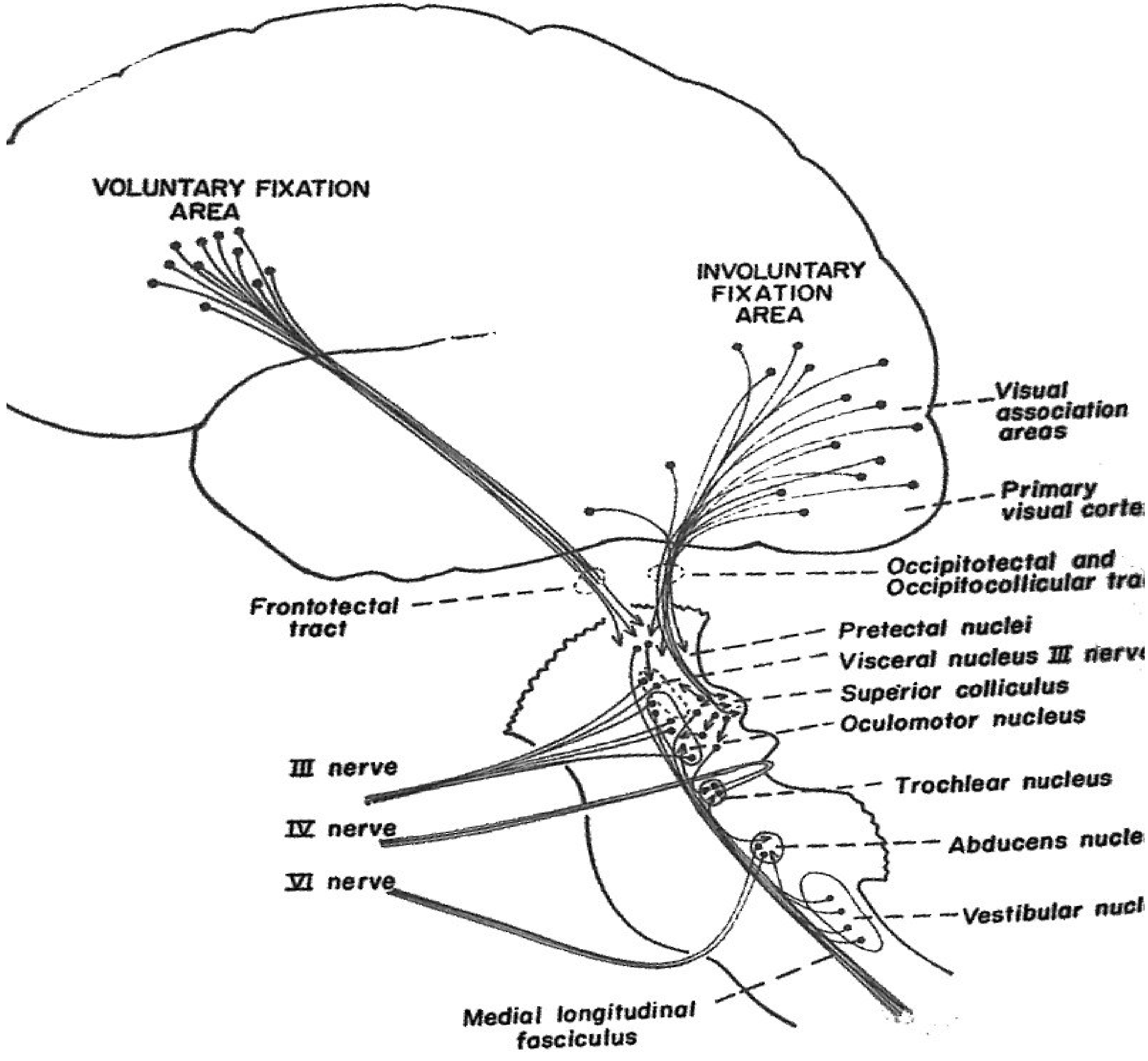
Geometry of Orbits and Muscle Planes

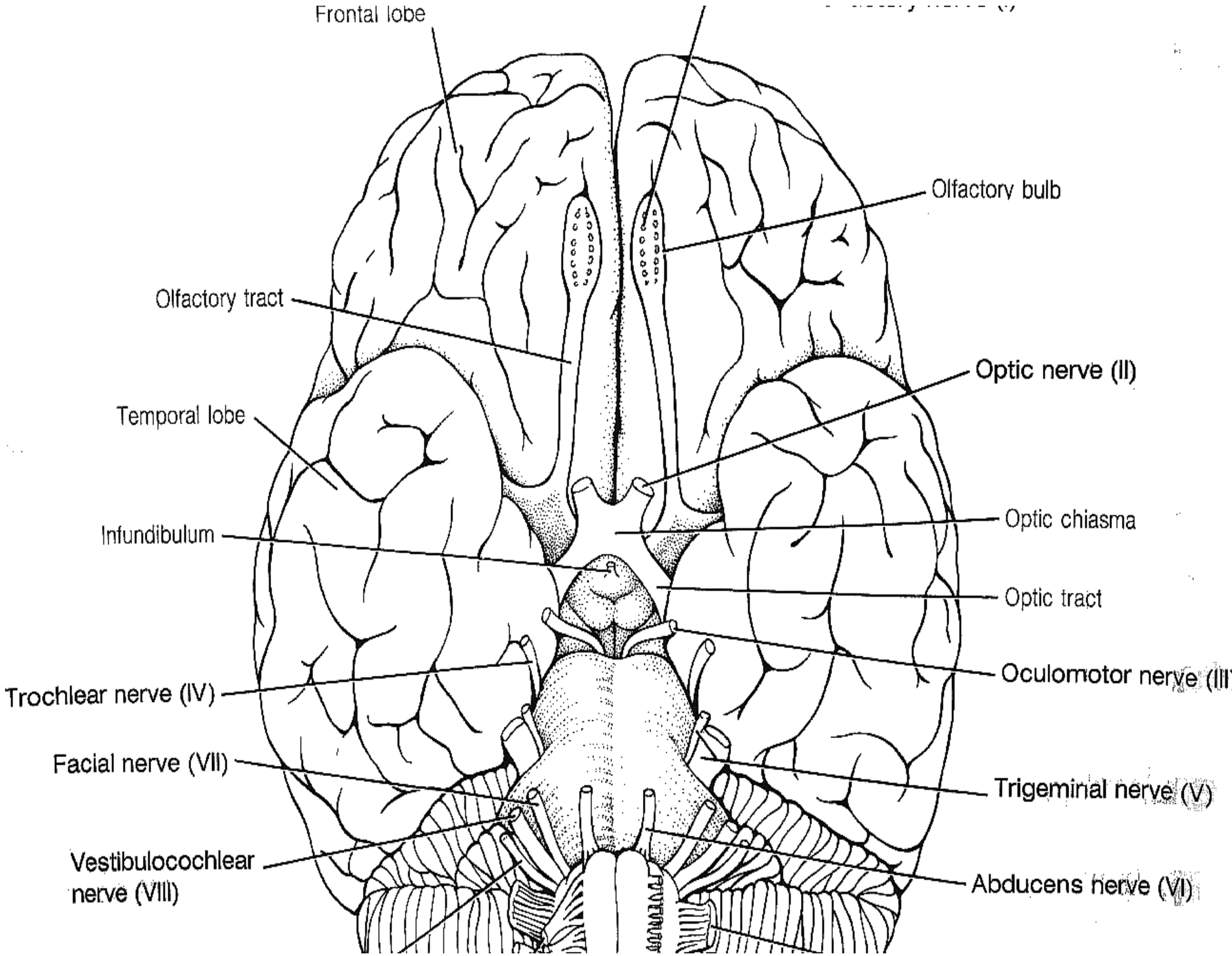


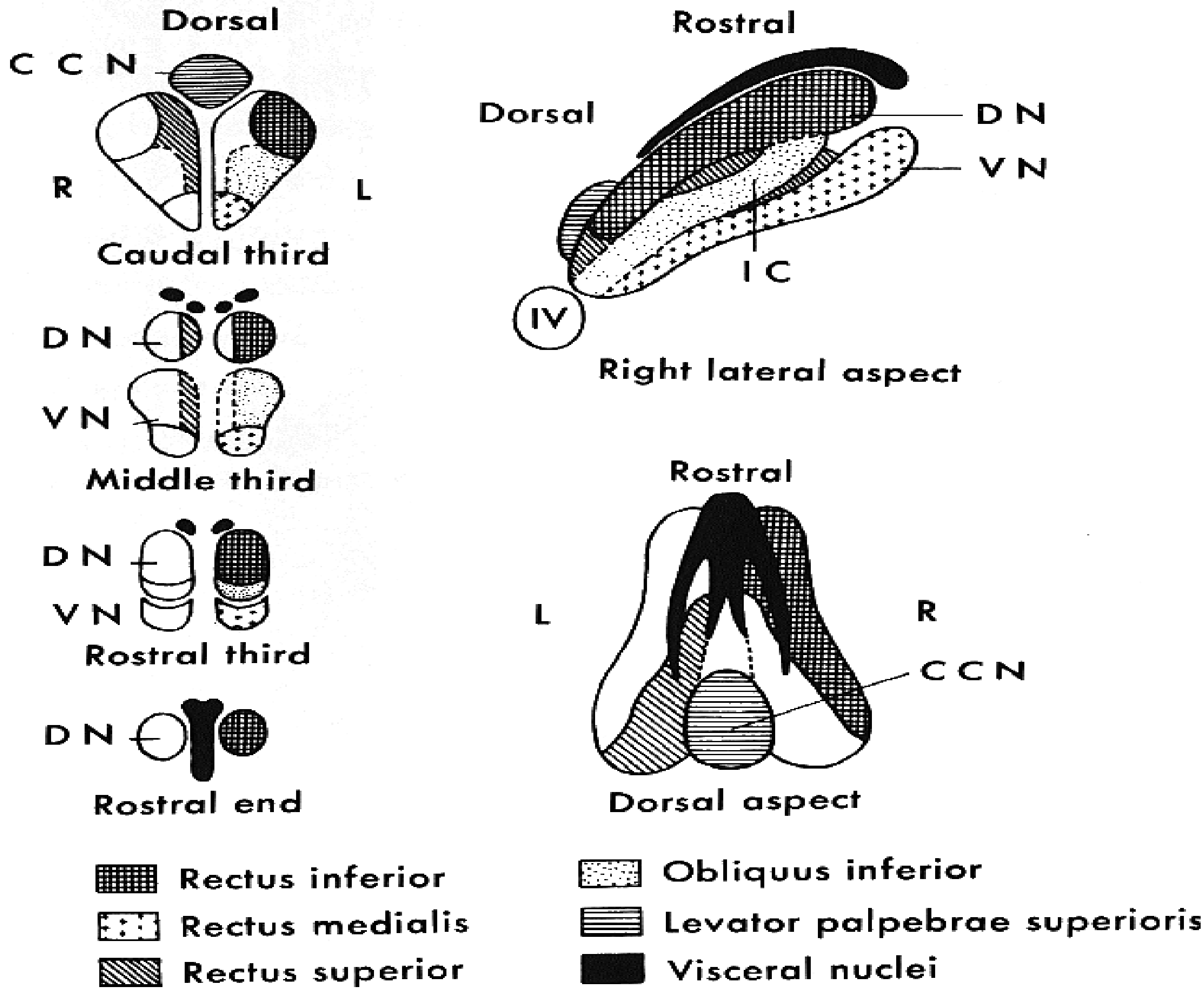

A
45deg
0deg
B
45deg
0deg
Pulley


Rotational Axis
Straight Ahead
Insert.
Pulley
Rotational Axis
α/2
Listing's Law
Saccades & Pursuit
α
α/2
D1
D2
D1 = D2
Rotational Axis
α/4
Half Listing's Law
Vestibulo-ocular
Reflex
α
α/4
D1
D2
D1 = 3 D2

Brain stem sites of cranial nerves- Final Common Pathway




Frontal lobe
Olfactory bulb
Olfactory tract
Optic nerve (II)
Temporal lobe
Optic chiasma
Infundibulum
Optic tract
Oculomotor nerve (III)
Trochlear nerve (IV)
Facial nerve (VII)
Trigeminal nerve (V)
Vestibulocochlear nerve (VIII)
Abducens nerve (VI)


Dorsal
C C N
R
L
Caudal third
D N
V N
Middle third
D N
V N
Rostral third
D N
Rostral end
Rostral
Dorsal
D N
V N
I C
IV
Right lateral aspect
Rostral
L
R
C C N
Dorsal aspect
Rectus inferior
Rectus medialis
Rectus superior
Obliquus inferior
Levator palpebrae superioris
Visceral nuclei