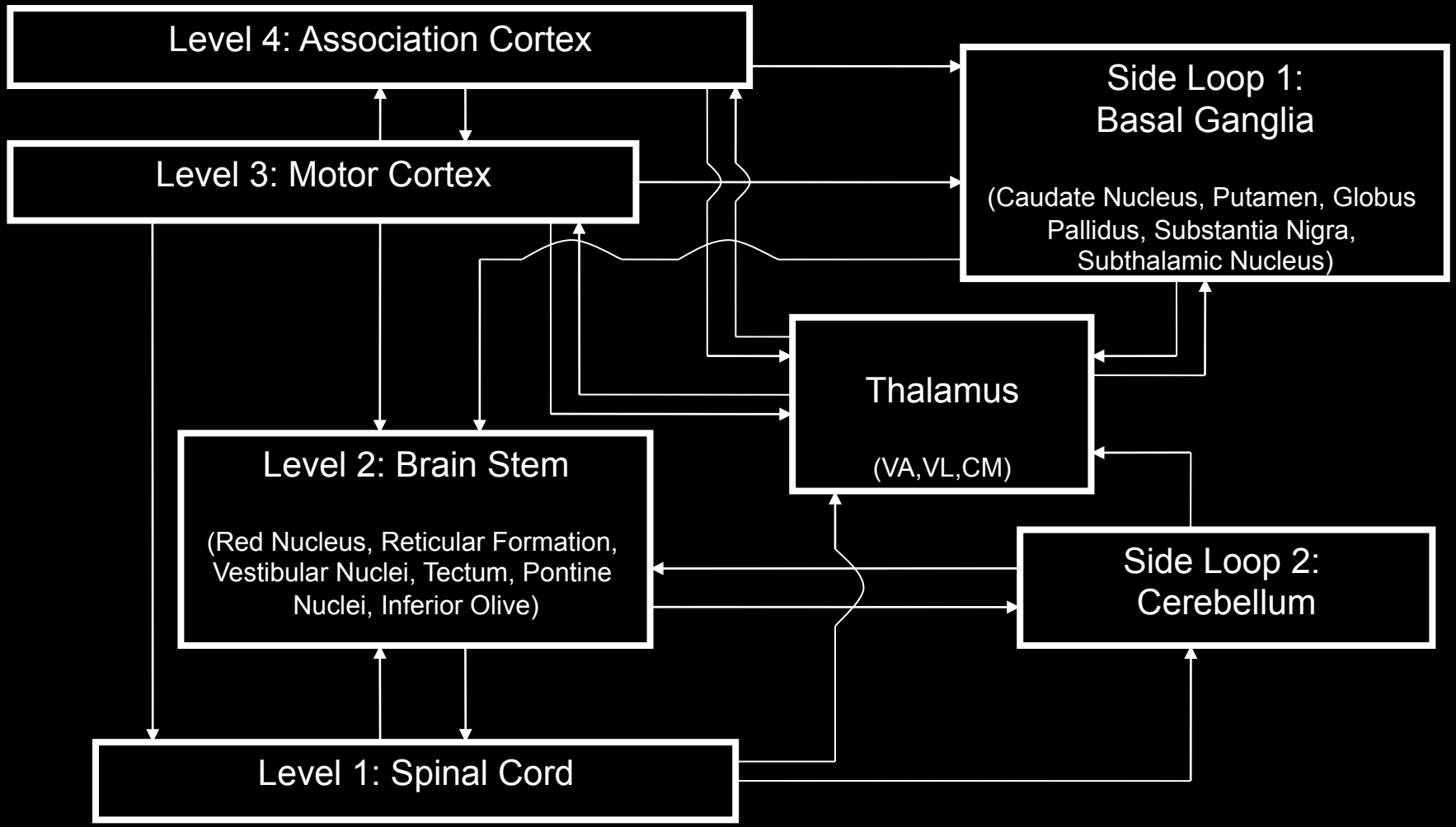
Motor Systems: Lecture 3
The Cerebellum

Michael S. Beauchamp, Ph.D.
Assistant Professor
Department of Neurobiology and Anatomy
University of Texas Health Science Center at Houston
Houston, TX

Michael.S.Beauchamp@uth.tmc.edu

Hierarchical Organization Of Motor Structures



Cerebellar Functions

10% of brain volume, > 50% of brain's neurons

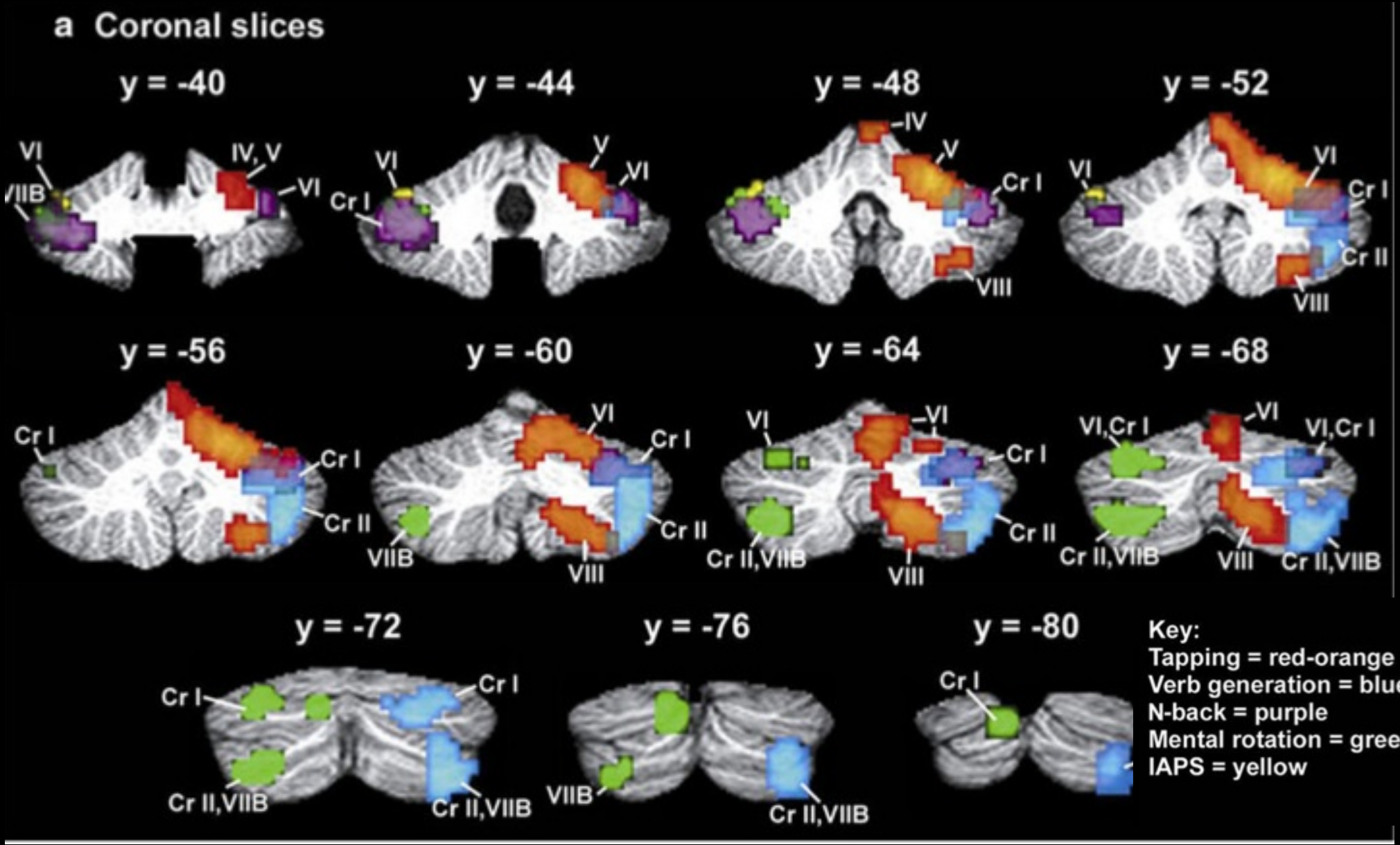
The coordination of movement and thought

Maintenance of balance and posture

Coordinated execution of voluntary movements

Motor learning

Cognitive functions: The coordination of thought

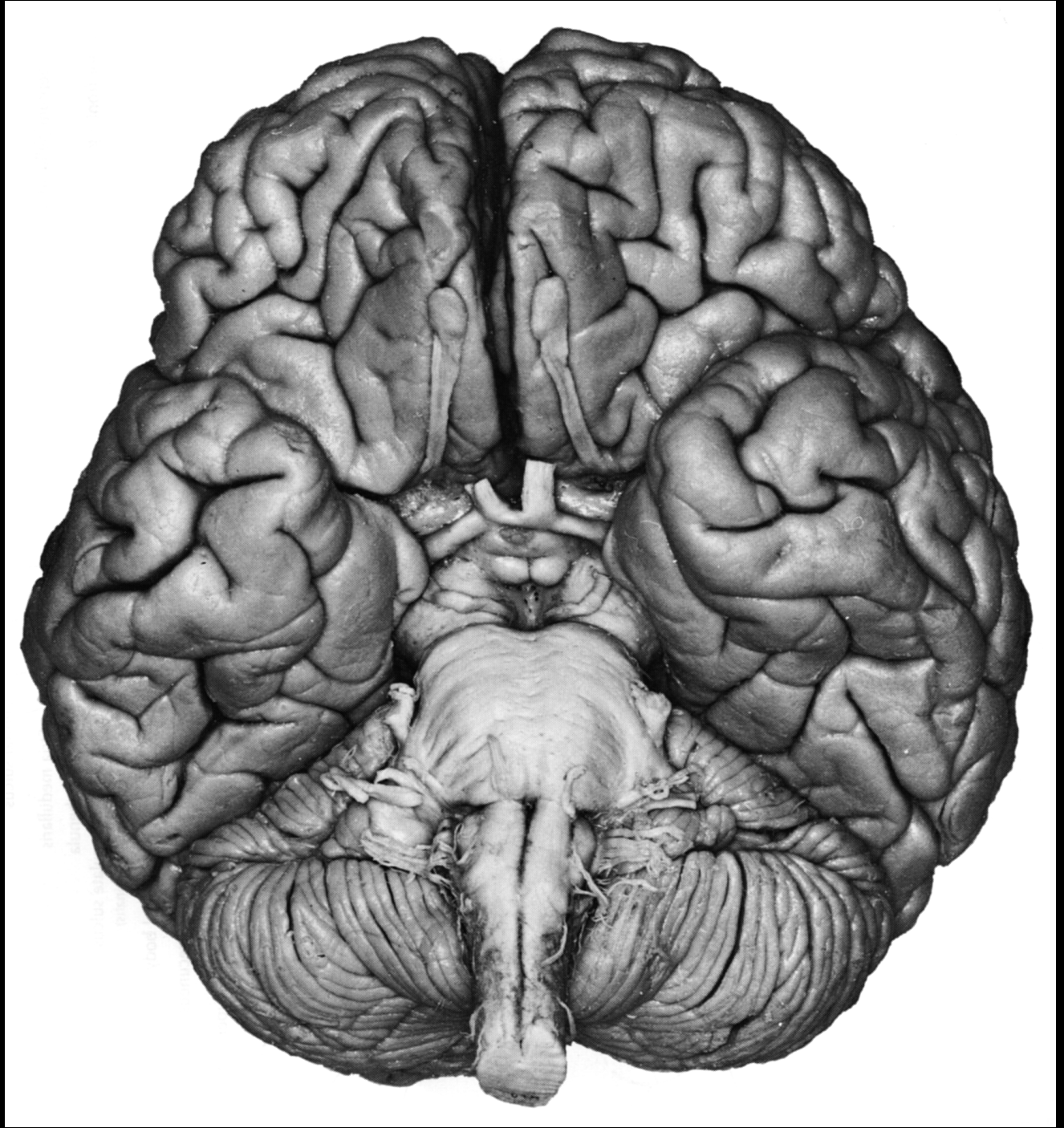

a Coronal slices
y = -40
VI
VIIB
IV, V
VI
y = -44
VI
Cr I
V
VI
y = -48
IV
V
Cr I
VIII
y = -52
VI
VI
Cr I
Cr II
VIII
y = -56
Cr I
Cr I
Cr II
y = -60
VI
Cr I
VIIB
Cr II
VIII
y = -64
VI
VI
Cr I
Cr II
Cr II,VIIB
VIII
y = -68
VI,Cr I
VI
VI,Cr I
Cr II,VIIB
VIII
Cr II,VIIB
y = -72
Cr I
Cr I
Cr II,VIIB
Cr II,VIIB
y = -76
VIIB
Cr II,VIIB
y = -80
Cr I
Key:
Tapping = red-orange
Verb generation = blue
N-back = purple
Mental rotation = green
IAPS = yellow

Reviewers

“the cerebellum couldn’t possibly be involved in cognitive functions or we would have discovered it long ago”

(1987)

Henrietta Leiner et al., in 1970s—noticed that cerebellar tract was much larger in humans than non-human primates



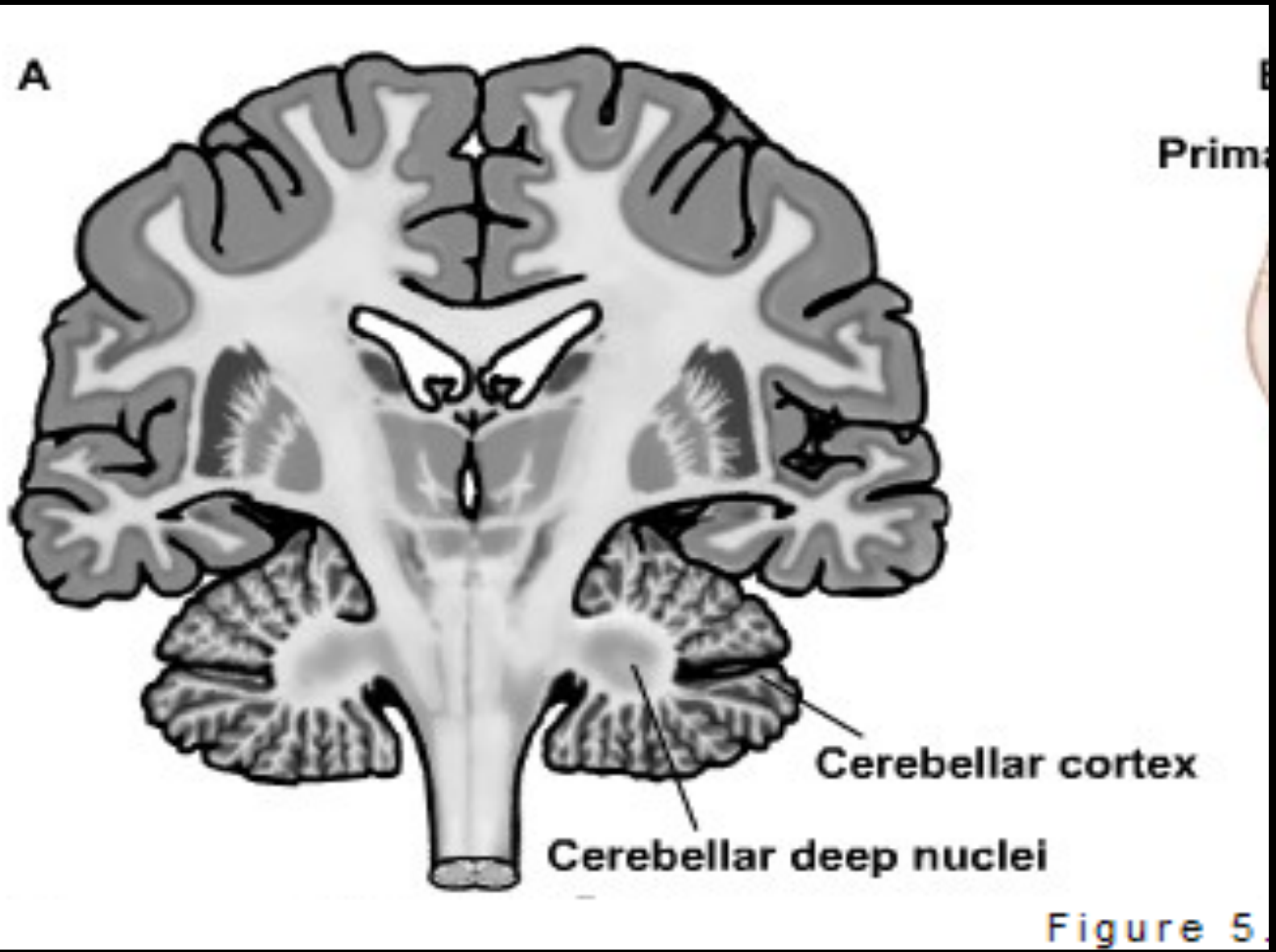


Figure 5

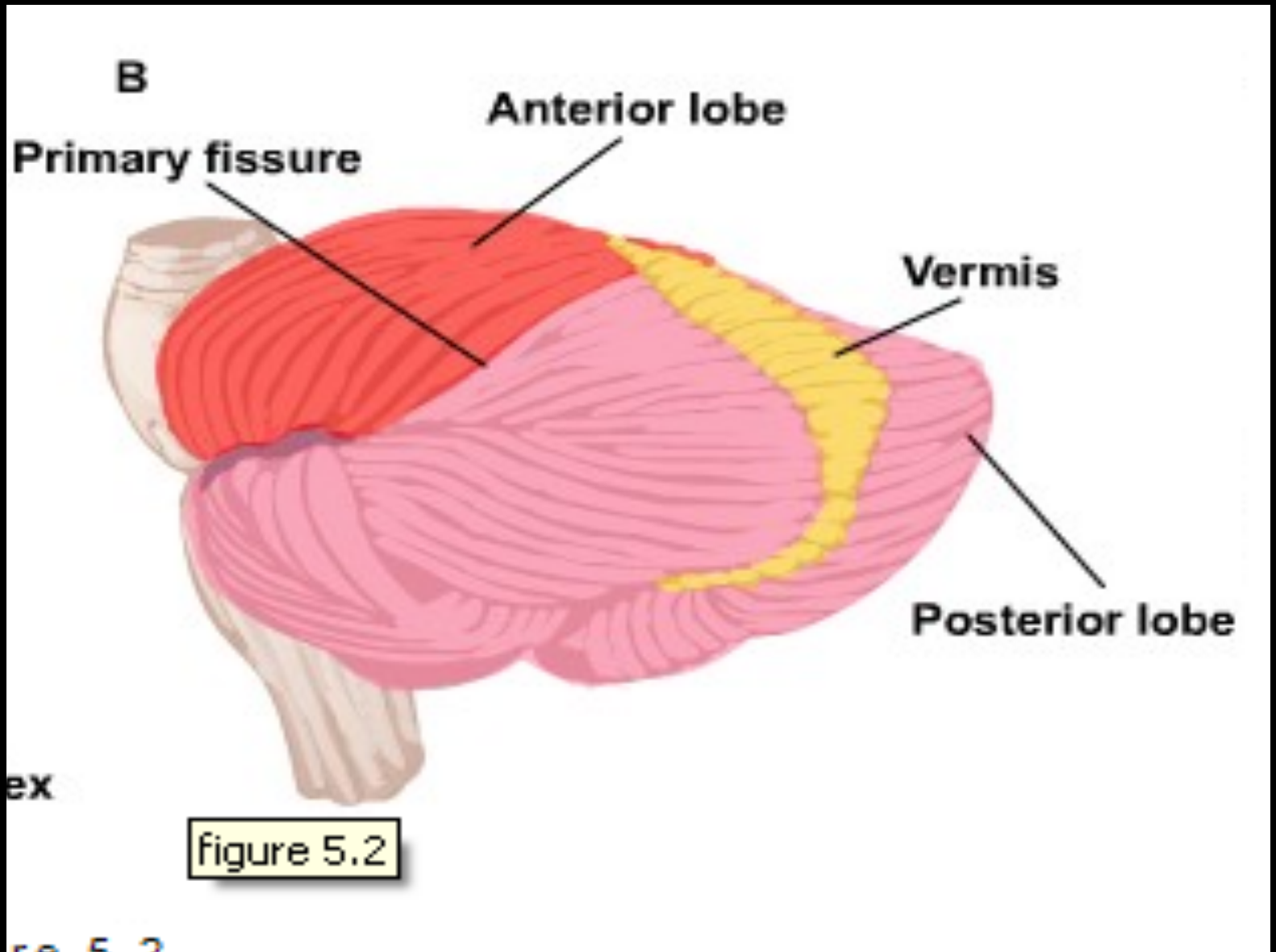
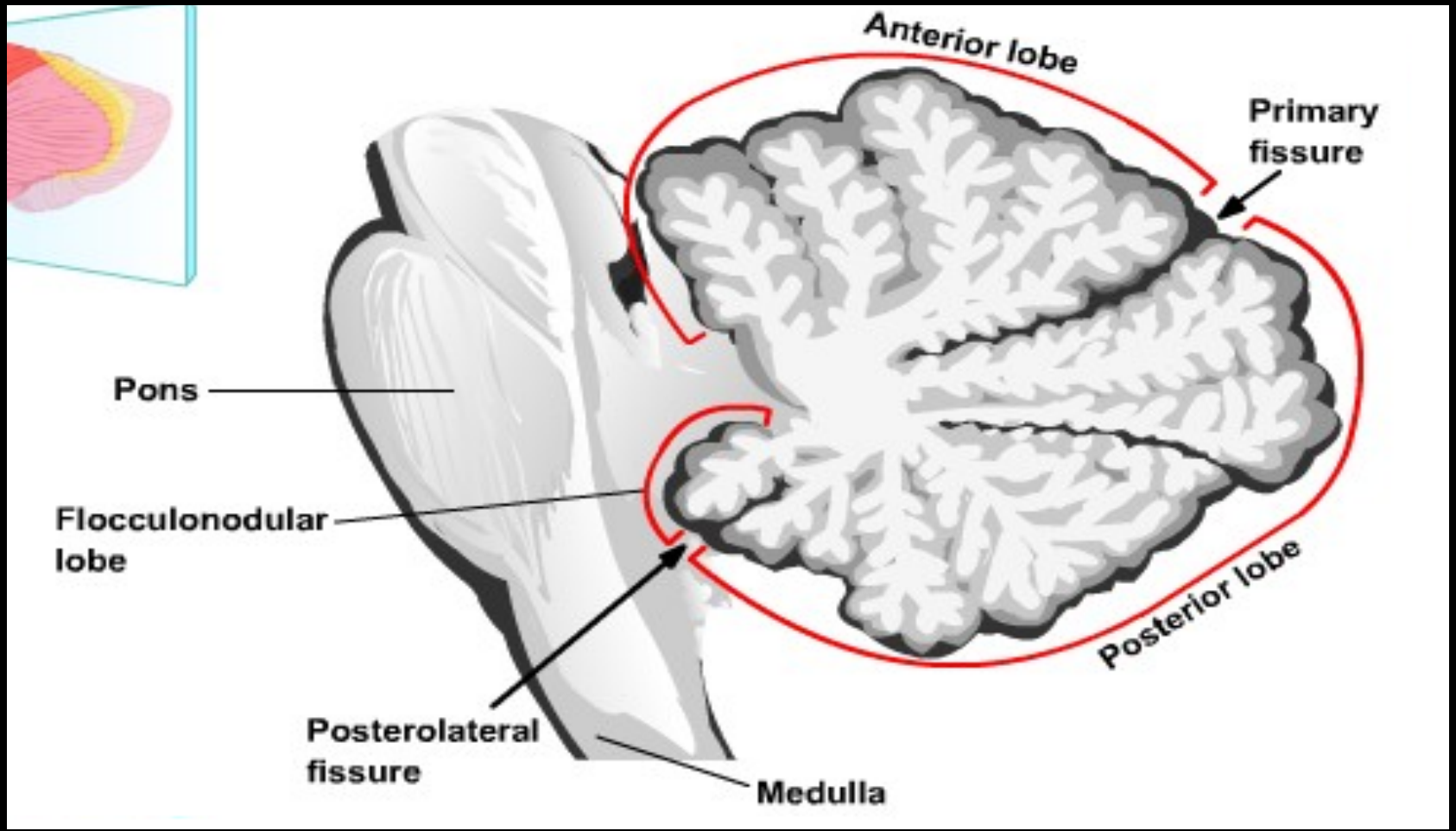
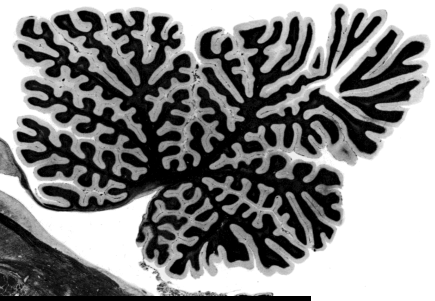
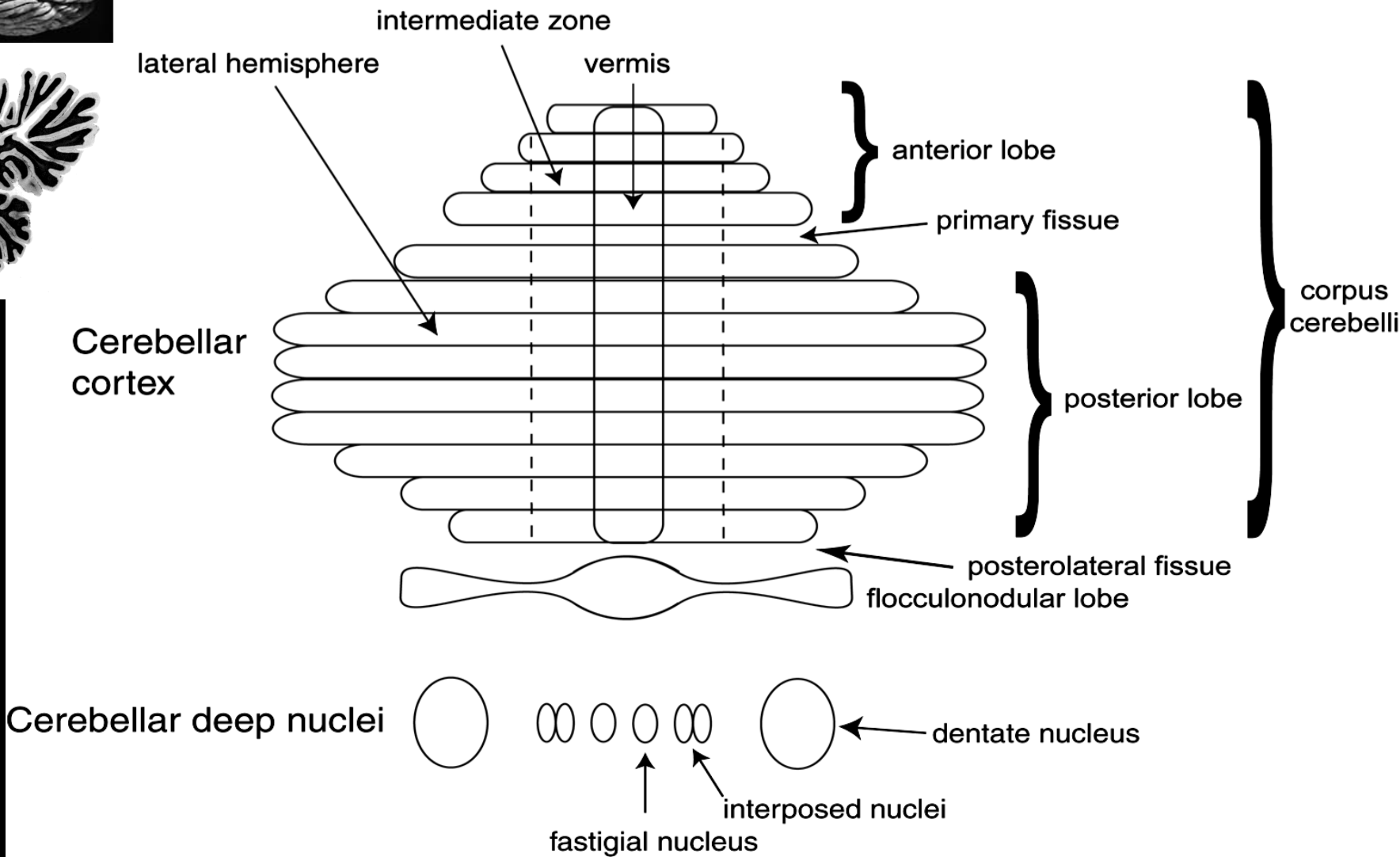


figure 5.2

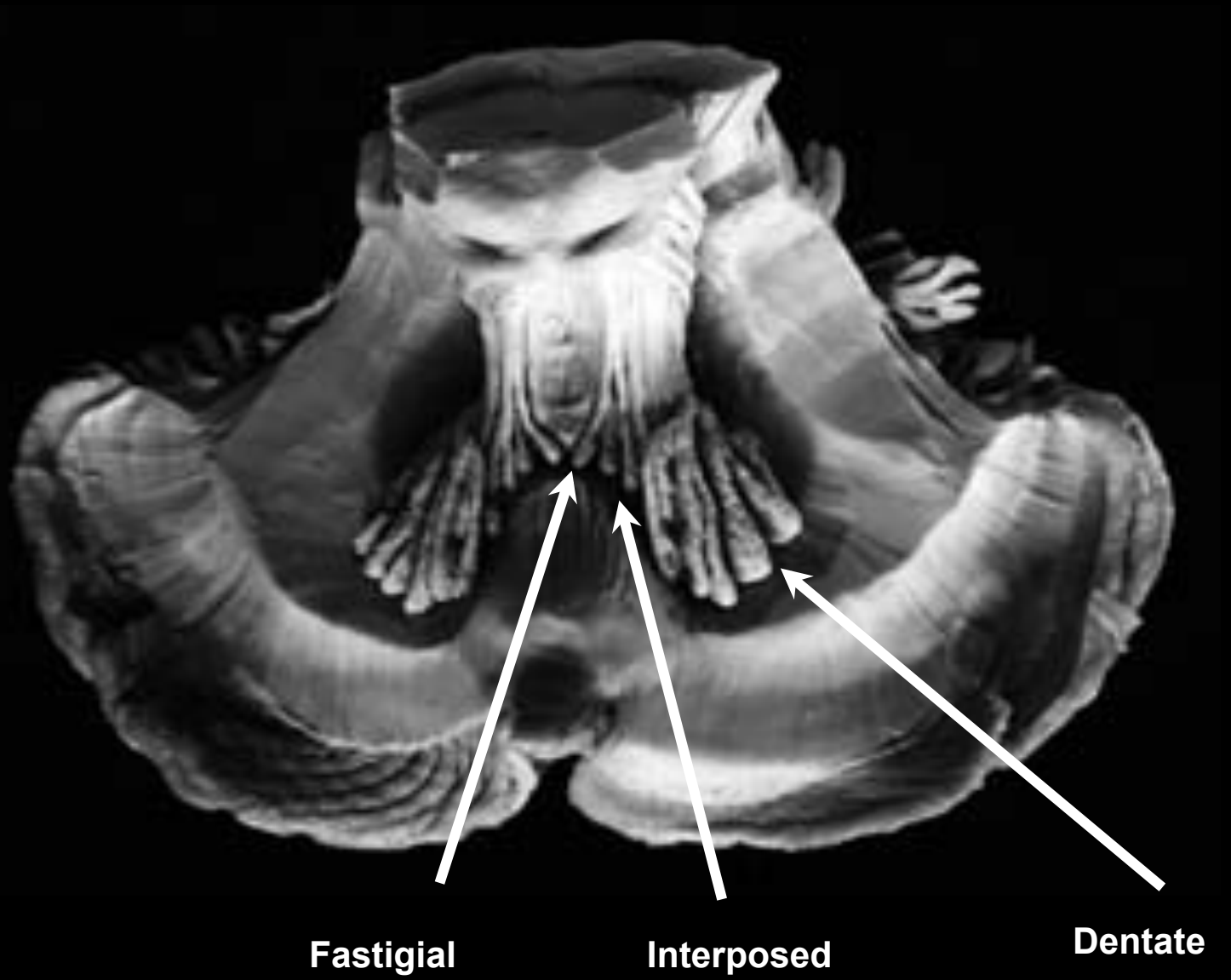

Anterior lobe
Primary fissure
Pons
Flocculonodular lobe
Posterior lobe
Posterolateral fissure
Medulla



Gross Anatomical Organization of Cerebellum

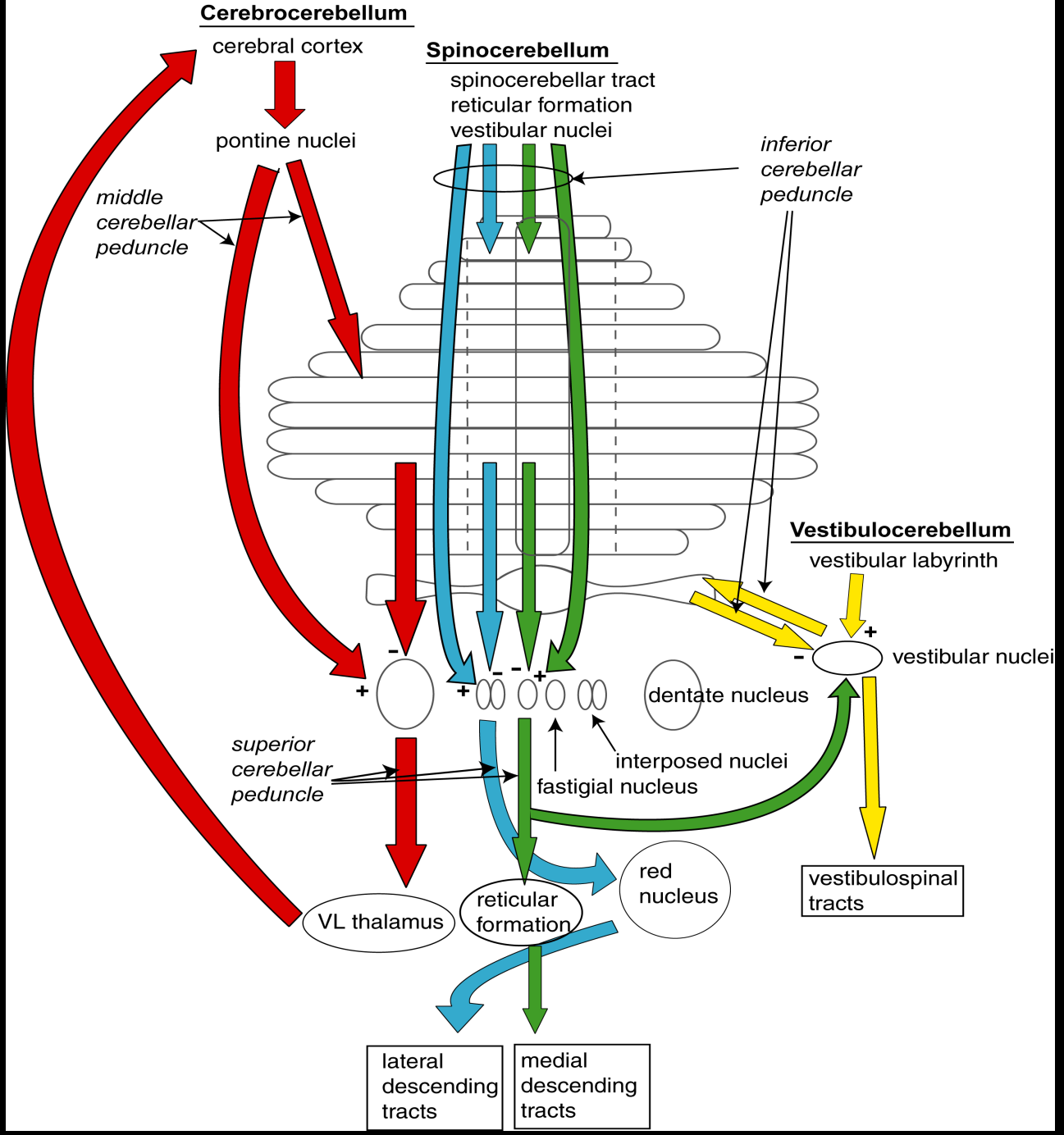


Deep Cerebellar Nuclei



Also
Lateral
Vestibular

Cerebellar Afferents and Efferents

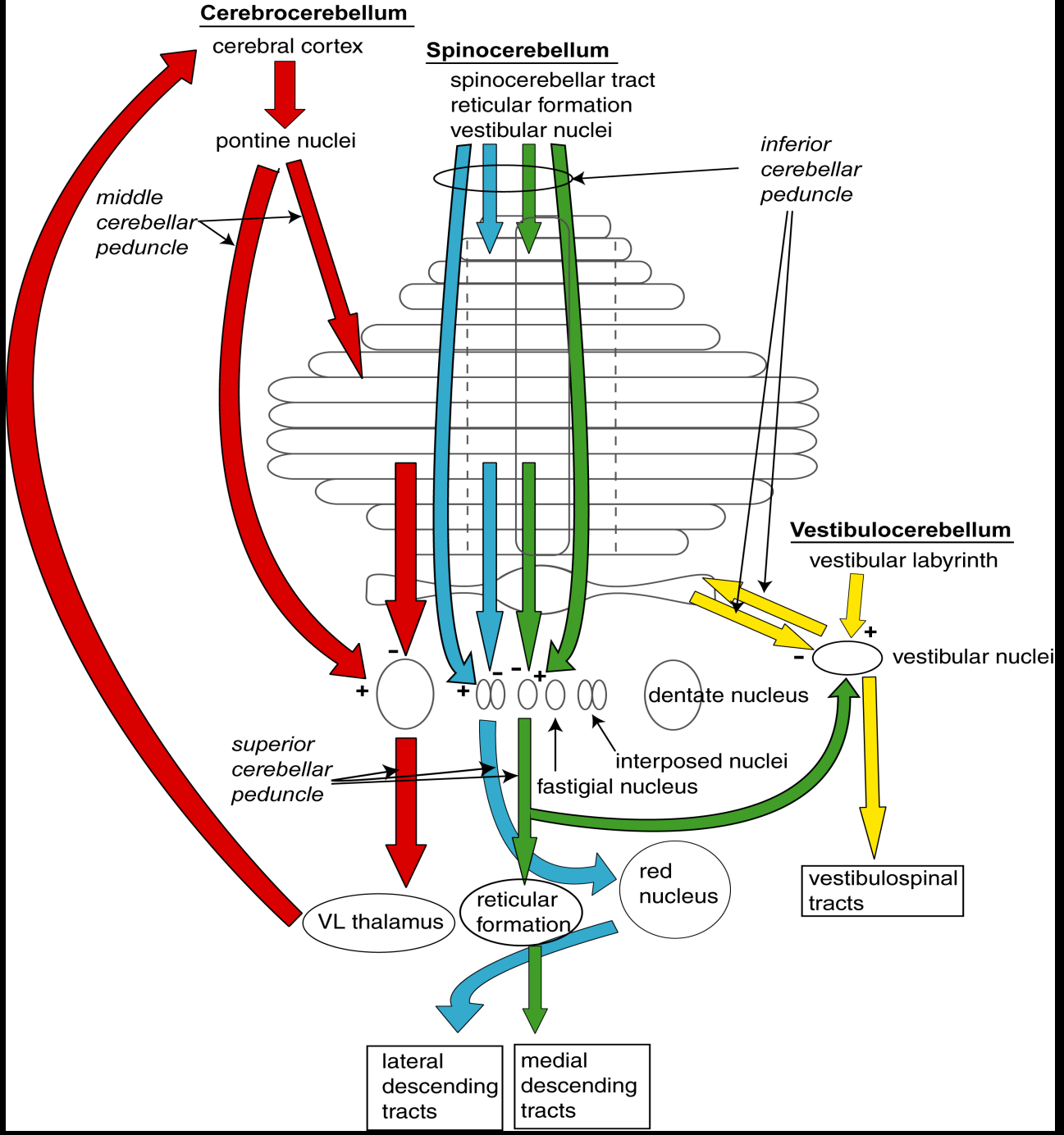


Deep Cerebellar Nuclei

Fastigial Nucleus

- inhibitory input from cerebellar cortex: vermis
- excitatory input: vestibular, proximal somatosensory, auditory, visual
- projects to vestibular nuclei, reticular formation

Cerebellar Afferents and Efferents



Deep Cerebellar Nuclei

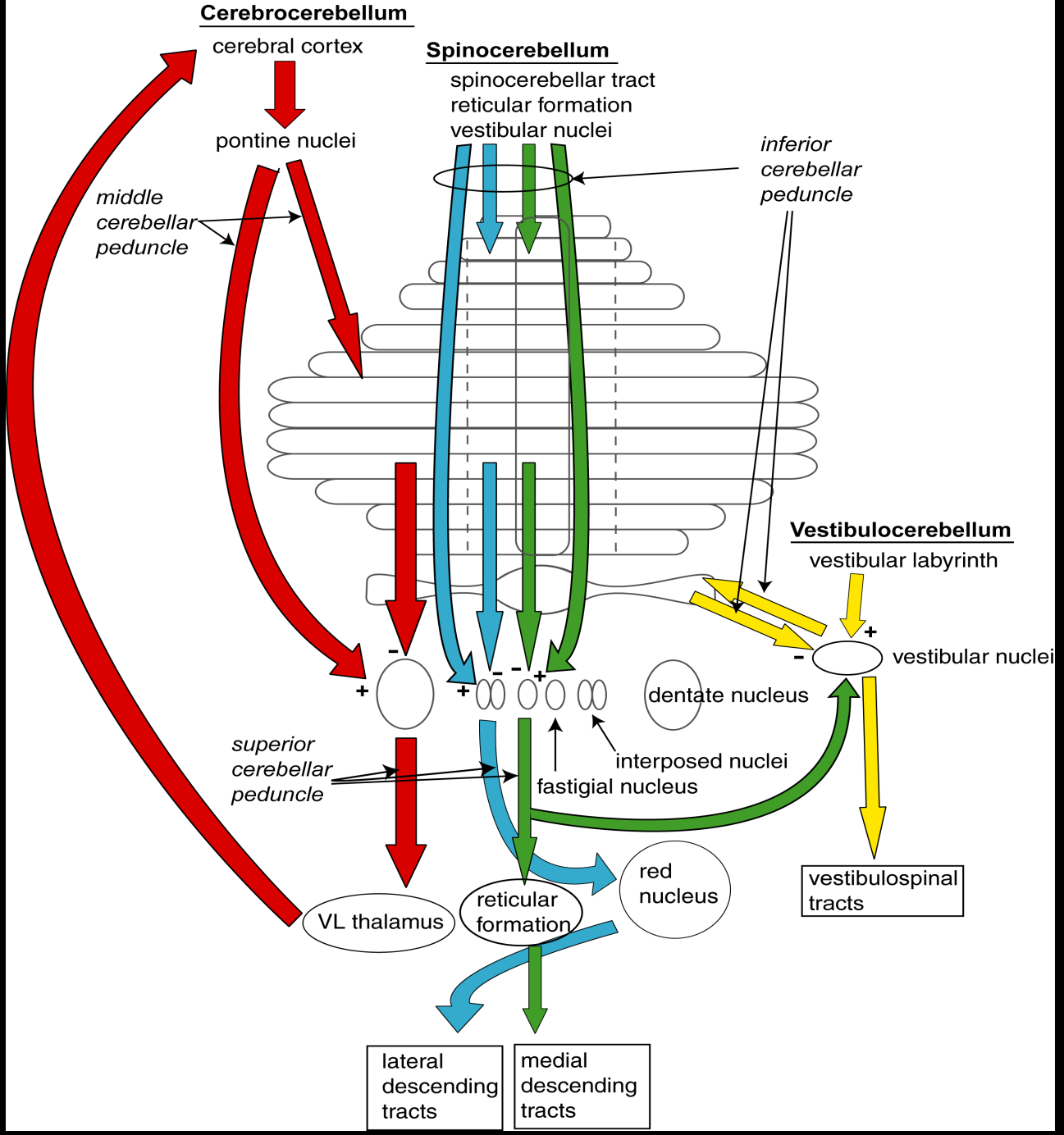
Fastigial Nucleus

- inhibitory input from cerebellar cortex : vermis
- excitatory input: vestibular, proximal somatosensory, auditory, visual
- projects to vestibular nuclei, reticular formation

Interposed

- inhibitory input from cerebellar cortex : intermediate zone
- excitatory input : spinal, proximal somatosensory, auditory, visual
- projects to contralateral red nucleus

Cerebellar Afferents and Efferents



Deep Cerebellar Nuclei

Fastigial Nucleus

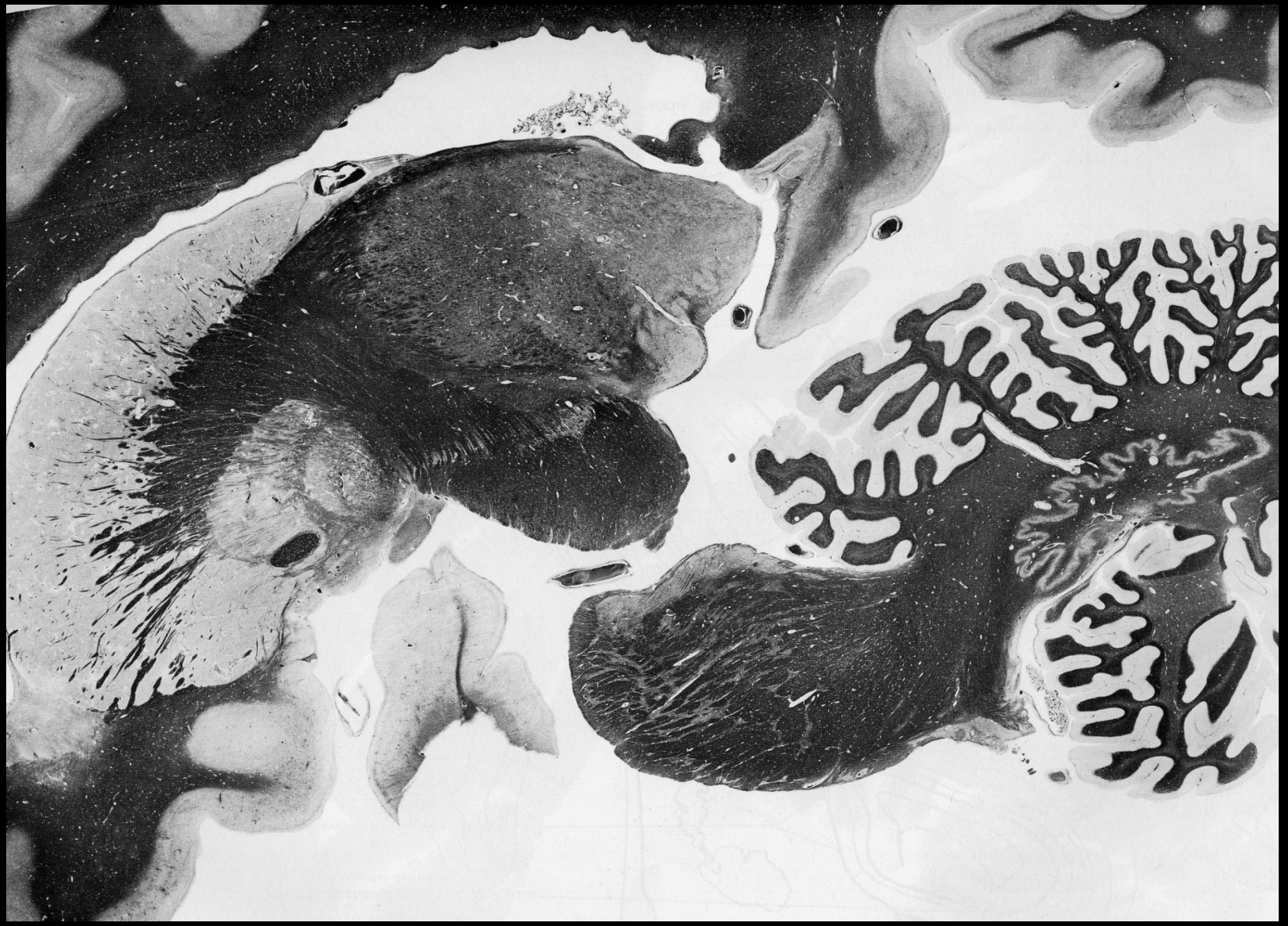
- inhibitory input from cerebellar cortex : vermis
- excitatory input: vestibular, proximal somatosensory, auditory, visual
- projects to vestibular nuclei, reticular formation

Interposed

- inhibitory input from cerebellar cortex : intermediate zone
- excitatory input : spinal, proximal somatosensory, auditory, visual
- projects to contralateral red nucleus

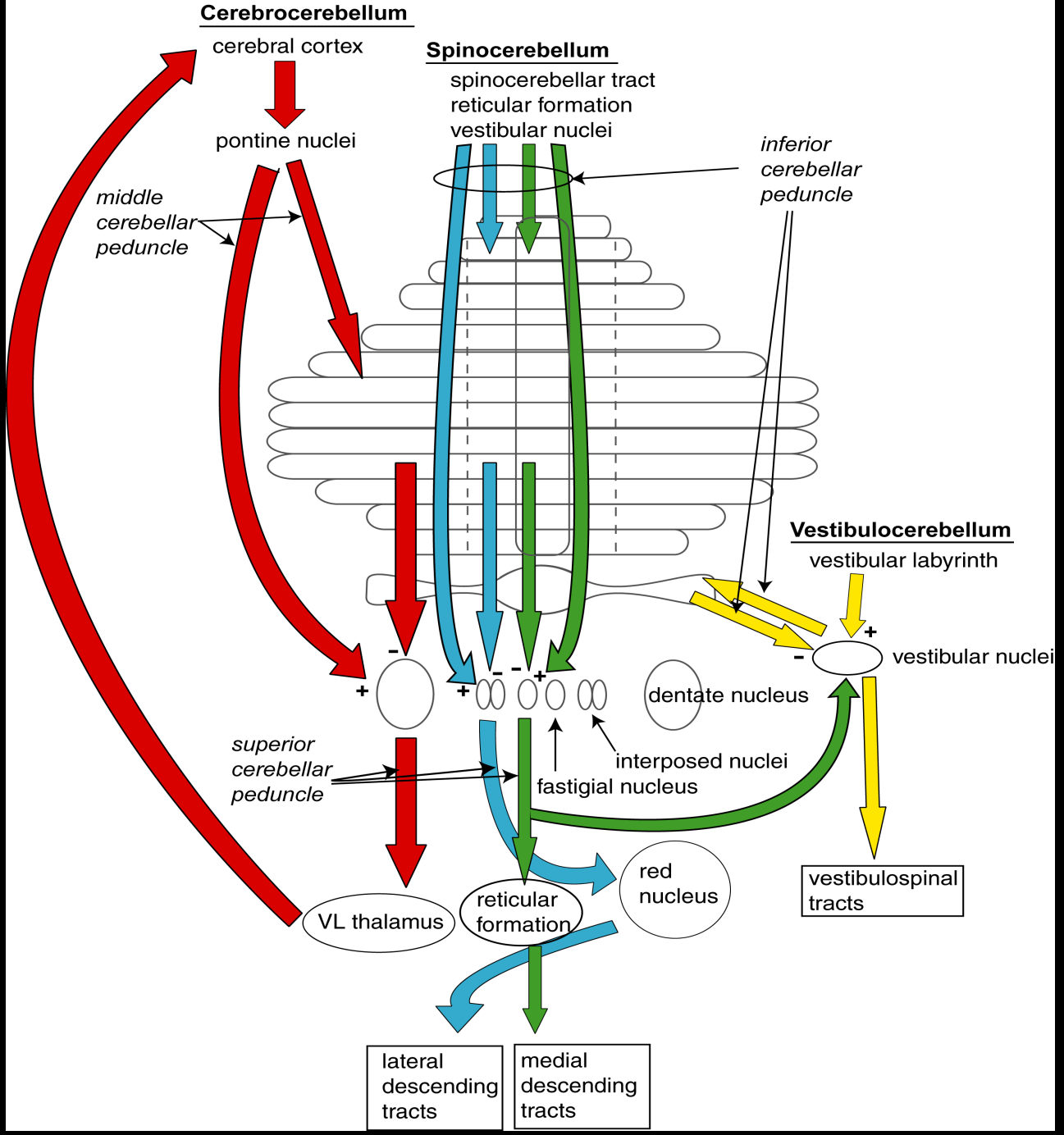
Dentate

- inhibitory input from cerebellar cortex : lateral hemisphere
- excitatory input: cortex via pontine nuclei
- projects to contralateral red nucleus, thalamus (VL)



DeArmond Fig. 81

Cerebellar Afferents and Efferents



Deep Cerebellar Nuclei

Fastigial Nucleus

- inhibitory input from cerebellar cortex : vermis
- excitatory input: vestibular, proximal somatosensory, auditory, visual
- projects to vestibular nuclei, reticular formation

Interposed

- inhibitory input from cerebellar cortex : intermediate zone
- excitatory input : spinal, proximal somatosensory, auditory, visual
- projects to contralateral red nucleus

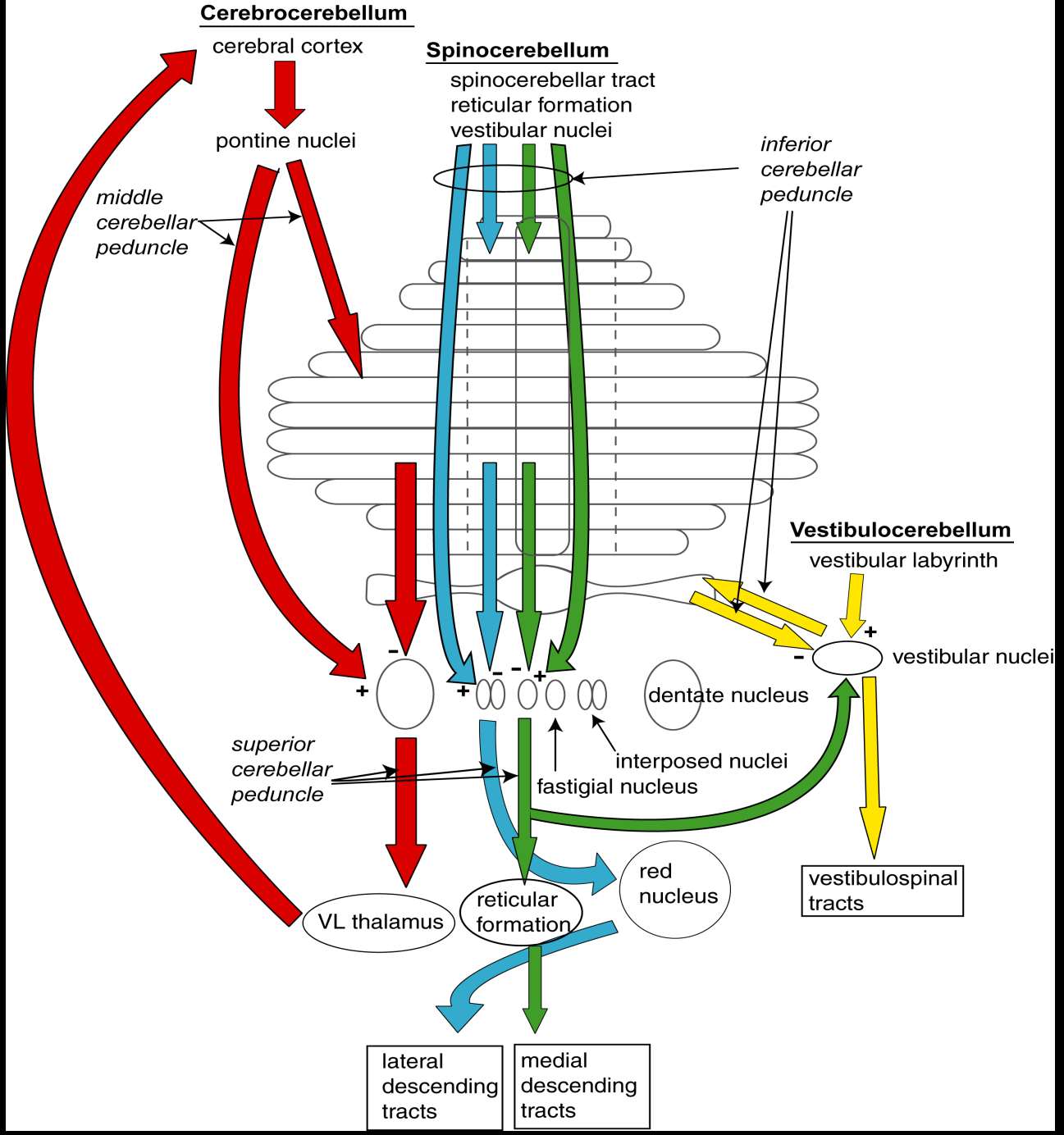
Dentate

- inhibitory input from cerebellar cortex : lateral hemisphere
- excitatory input: cortex via pontine nuclei
- projects to contralateral red nucleus, thalamus (VL)

Vestibular

- inhibitory input from cerebellar cortex : flocculonodular lobe
- excitatory input: vestibular labyrinth
- projects to motor nuclei

Cerebellar Afferents and Efferents



Cerebellar Peduncles

Input and output tracts of cerebellum

Inferior Cerebellar Peduncle (restiform body)
Primarily afferent fibers from medulla

Middle Cerebellar Peduncle (brachium pontis)
Primarily afferent fibers from pons

Superior Cerebellar Peduncle (brachium conjunctivum)
Primarily efferent fibers from the cerebellar nuclei

Cerebellum controls the IPSILATERAL side of the body

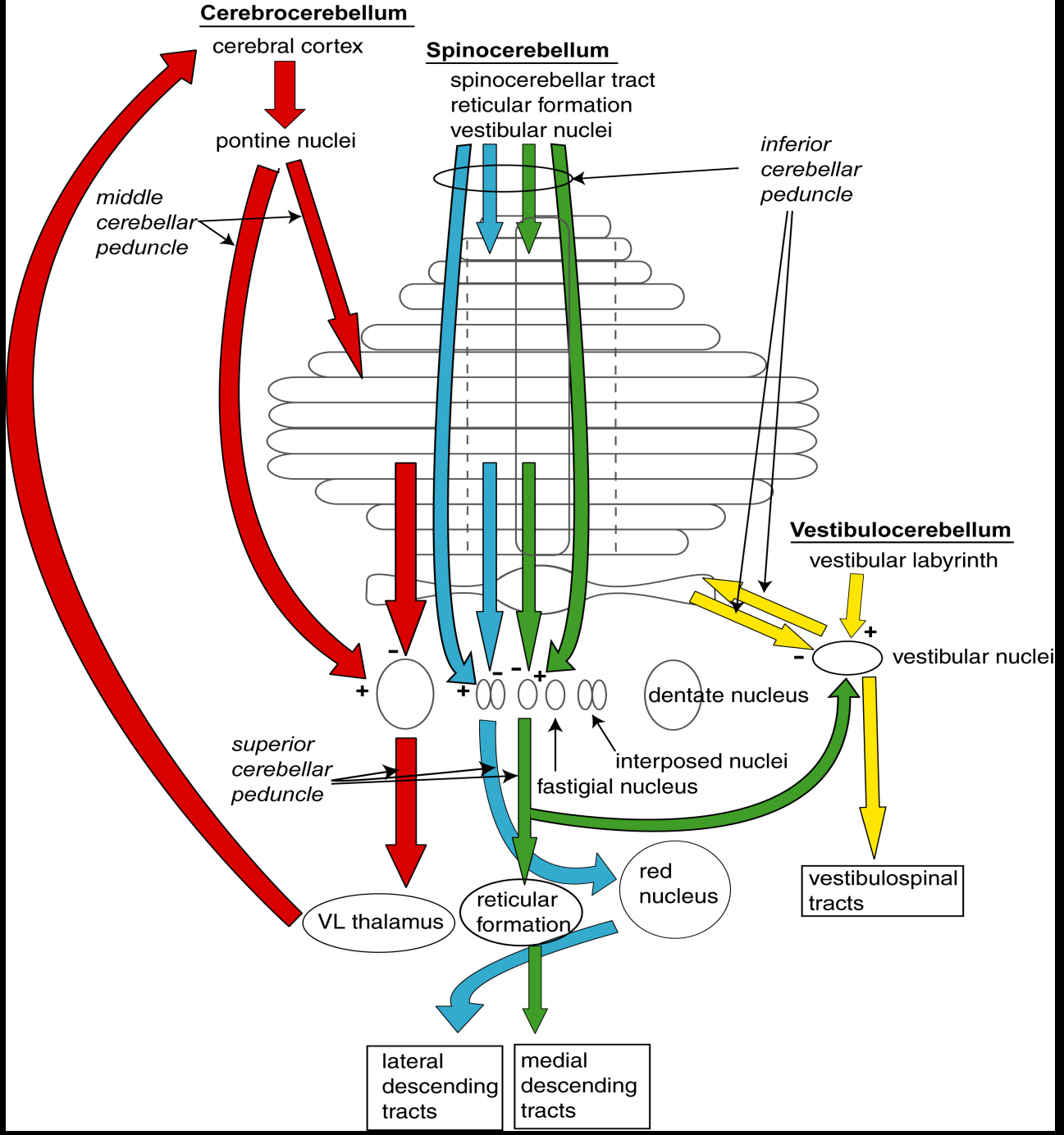
Functional Divisions of Cerebellum

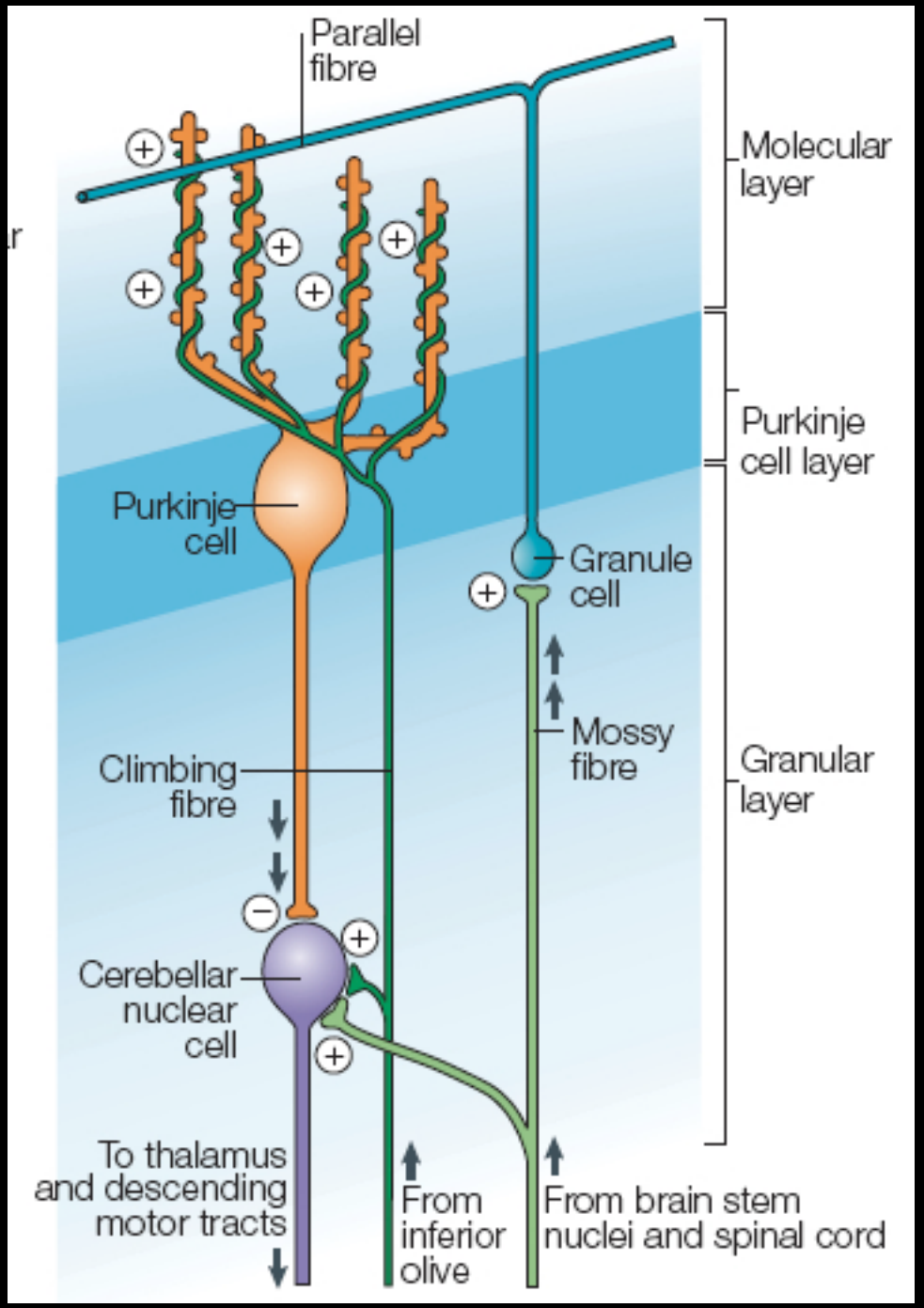
Vestibulocerebellum
- **flocculonodular lobe**
- **lateral vestibular nuclei**
- ***oldest part of cerebellum***
- ***postural and vestibular reflexes***

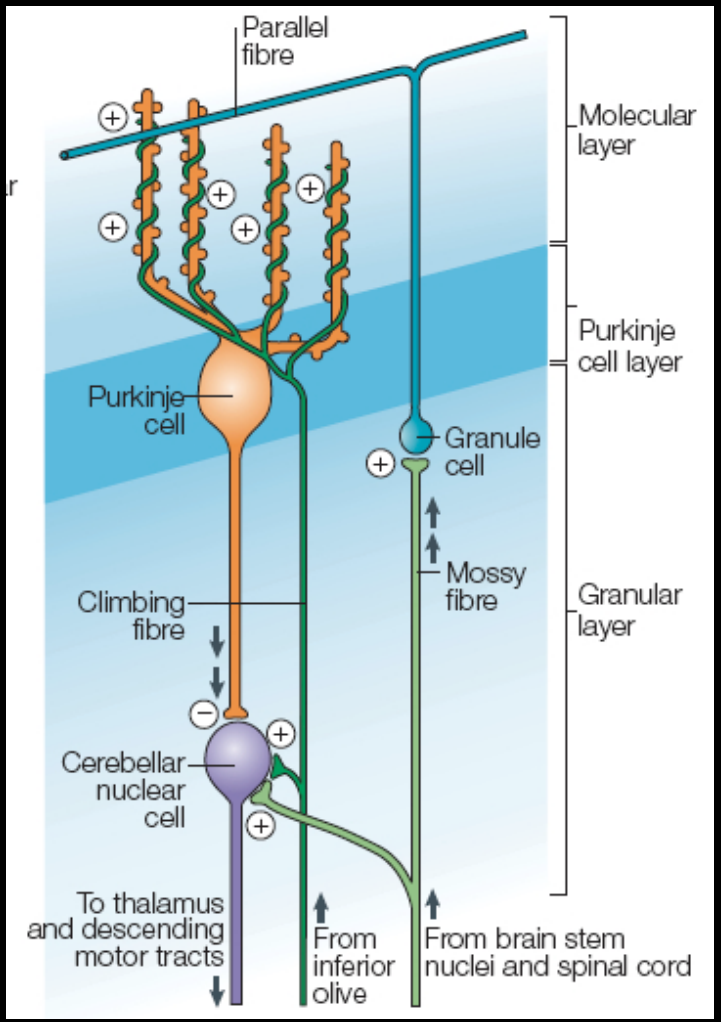
Spinocerebellum
- **vermis and intermediate zone**
- **fastigial and interposed nuclei**
- **motor coordination**

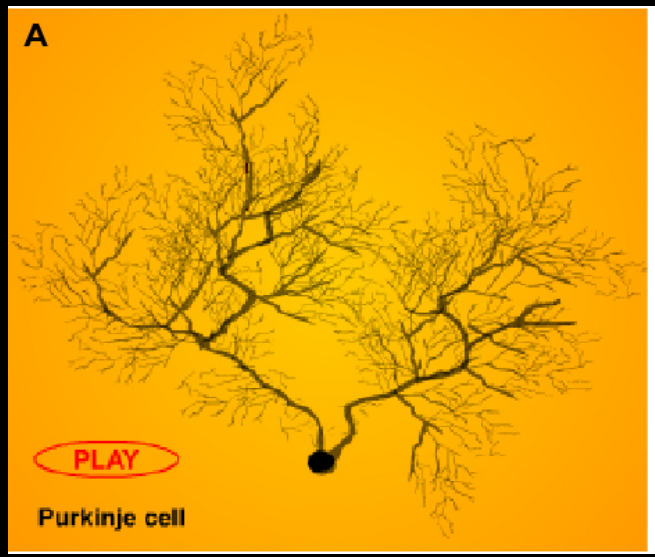
Cerebrocerebellum
- **lateral hemispheres**
- **dentate nuclei**
- **planning and timing of movements**

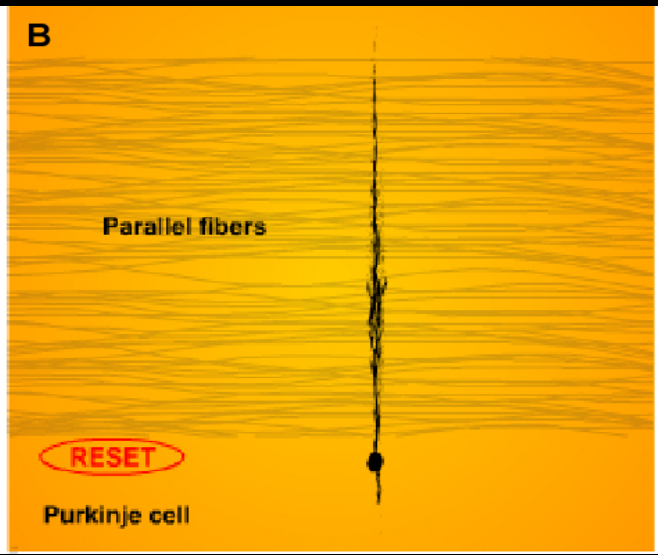
Cerebellar Afferents and Efferents



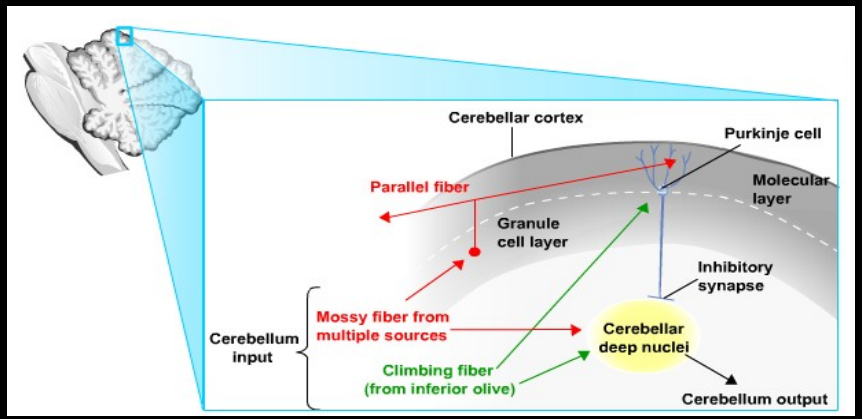

Parallel fibre
Molecular layer
Purkinje cell layer
Granular layer
Purkinje cell
Granule cell
Mossy fibre
Climbing fibre
Cerebellar nuclear cell
To thalamus and descending motor tracts
From inferior olive
From brain stem nuclei and spinal cord

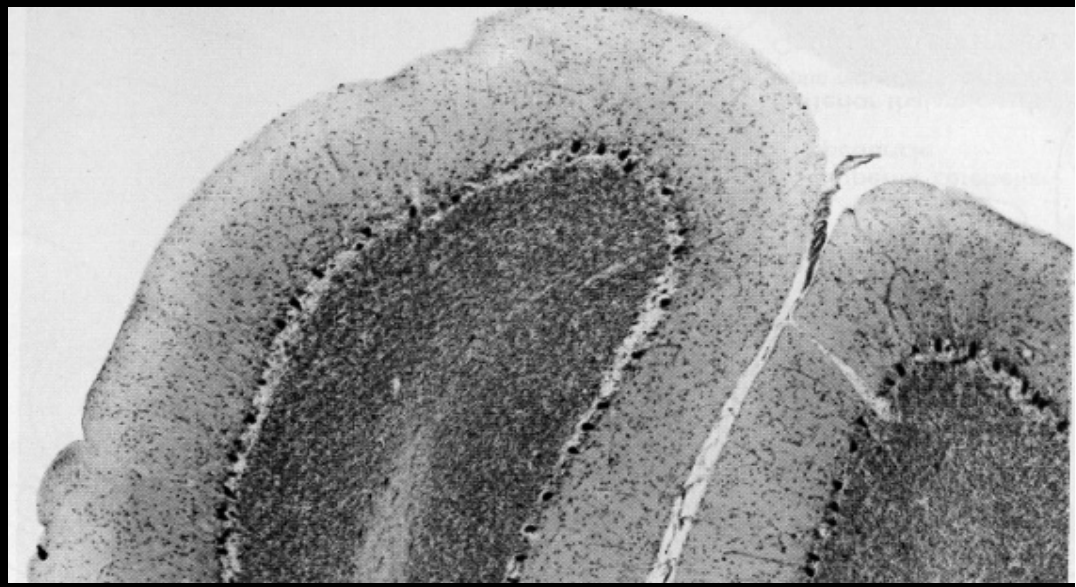

Parallel fibre
Molecular layer
Purkinje cell layer
Purkinje cell
Granule cell
Mossy fibre
Climbing fibre
Granular layer
Cerebellar nuclear cell
To thalamus and descending motor tracts
From inferior olive
From brain stem nuclei and spinal cord


A
PLAY
Purkinje cell

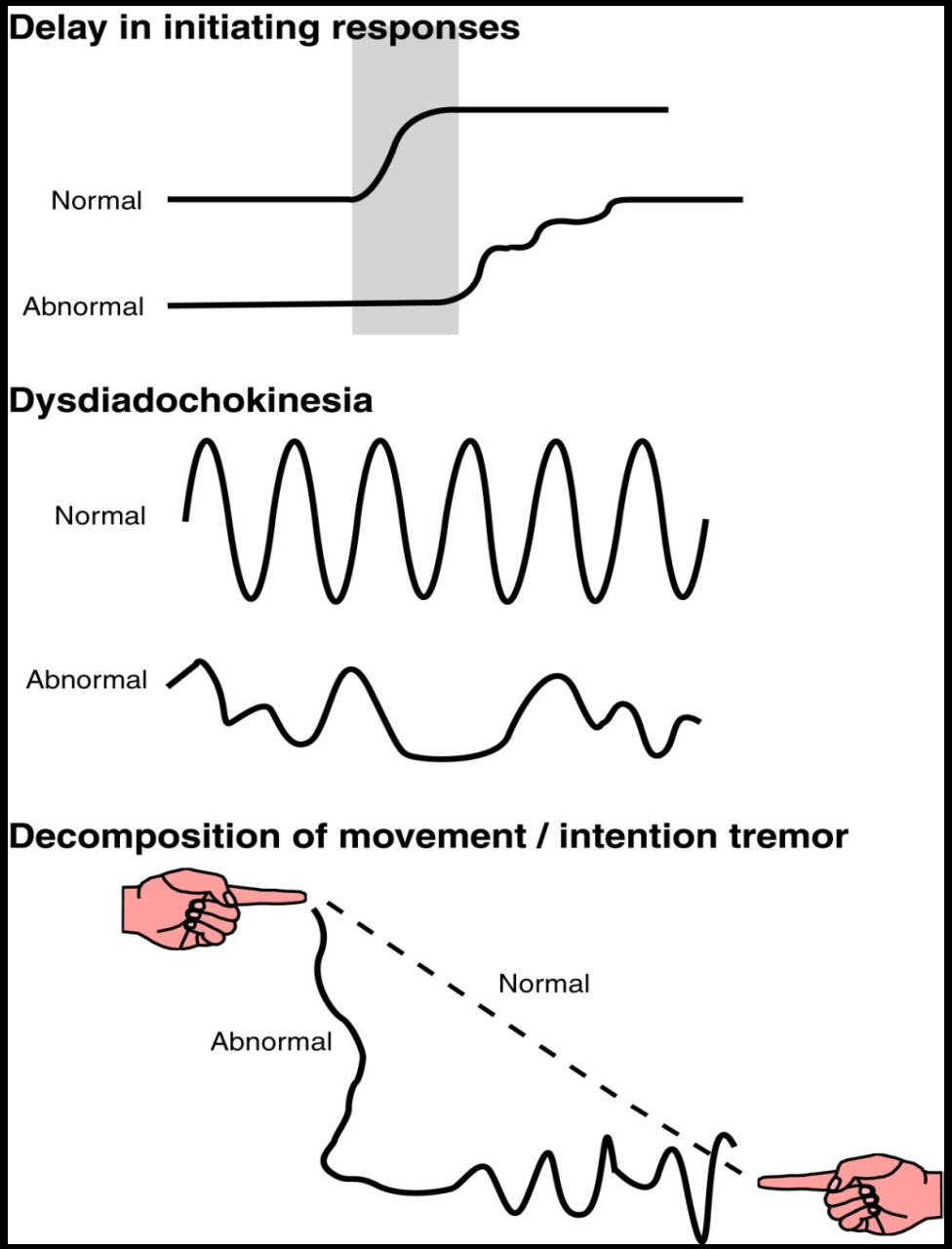

B
Parallel fibers
RESET
Purkinje cell

Internal Circuitry of Cerebellum





Cerebellum Produces Movement Disorders

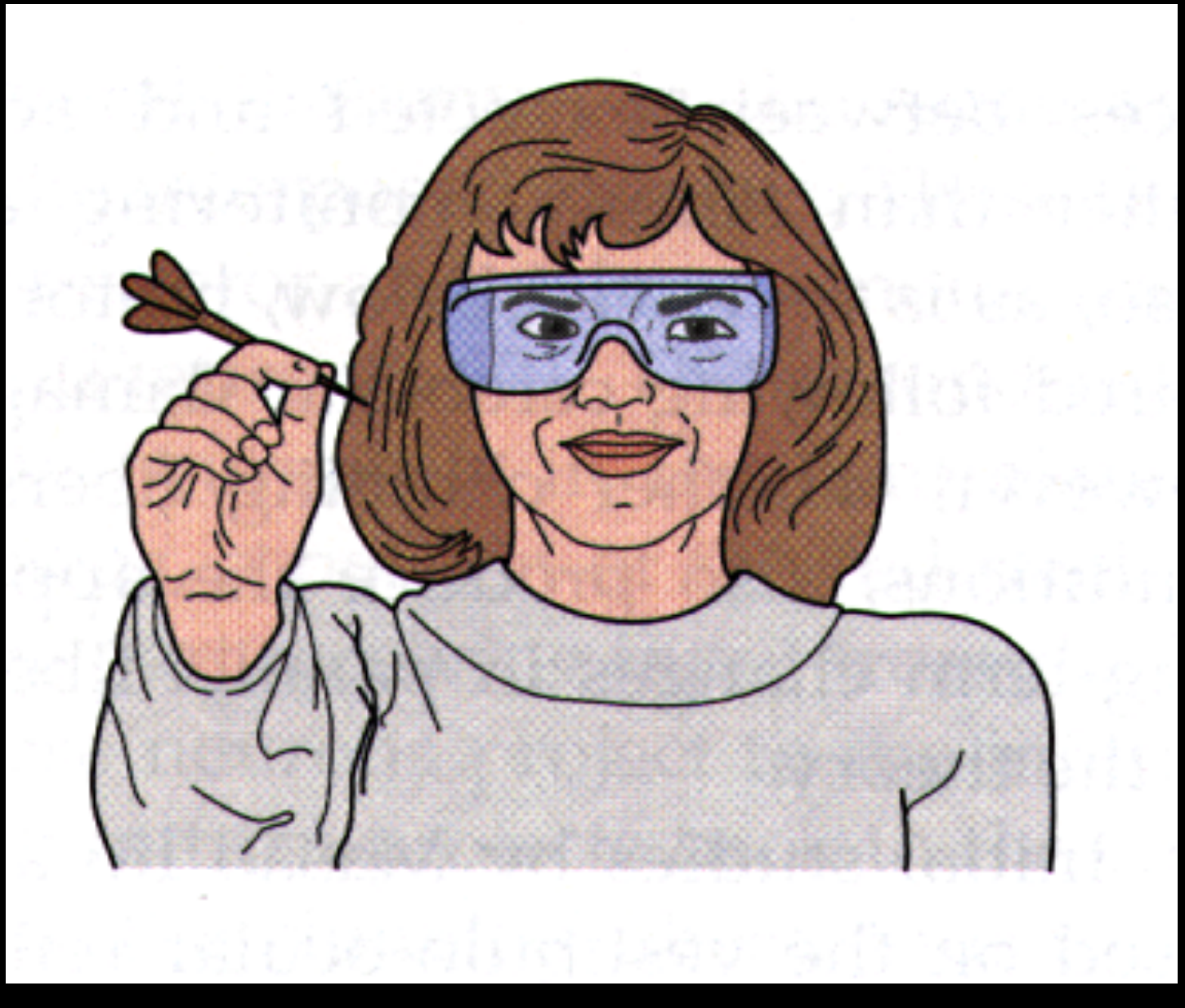


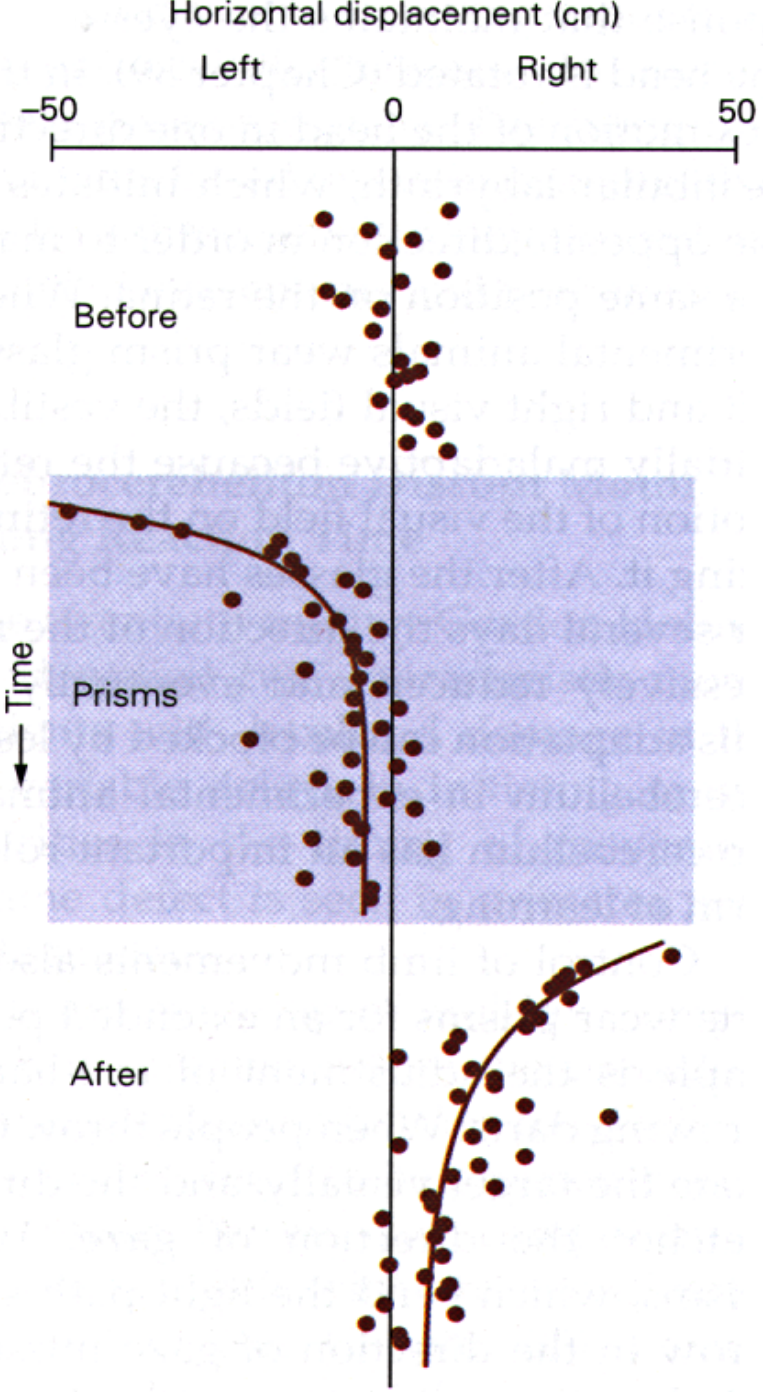
Cerebellum and Motor Learning

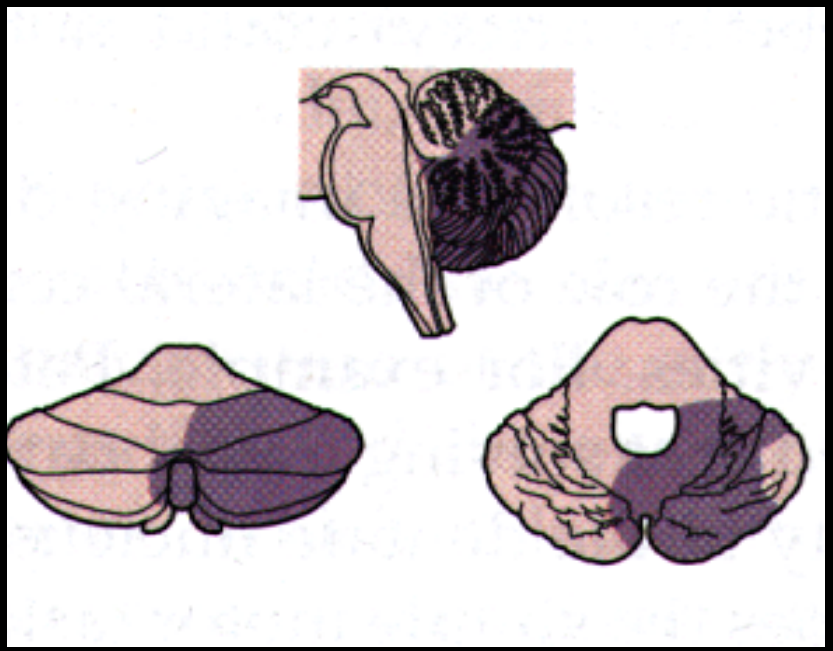
Vestibulo-ocular reflex

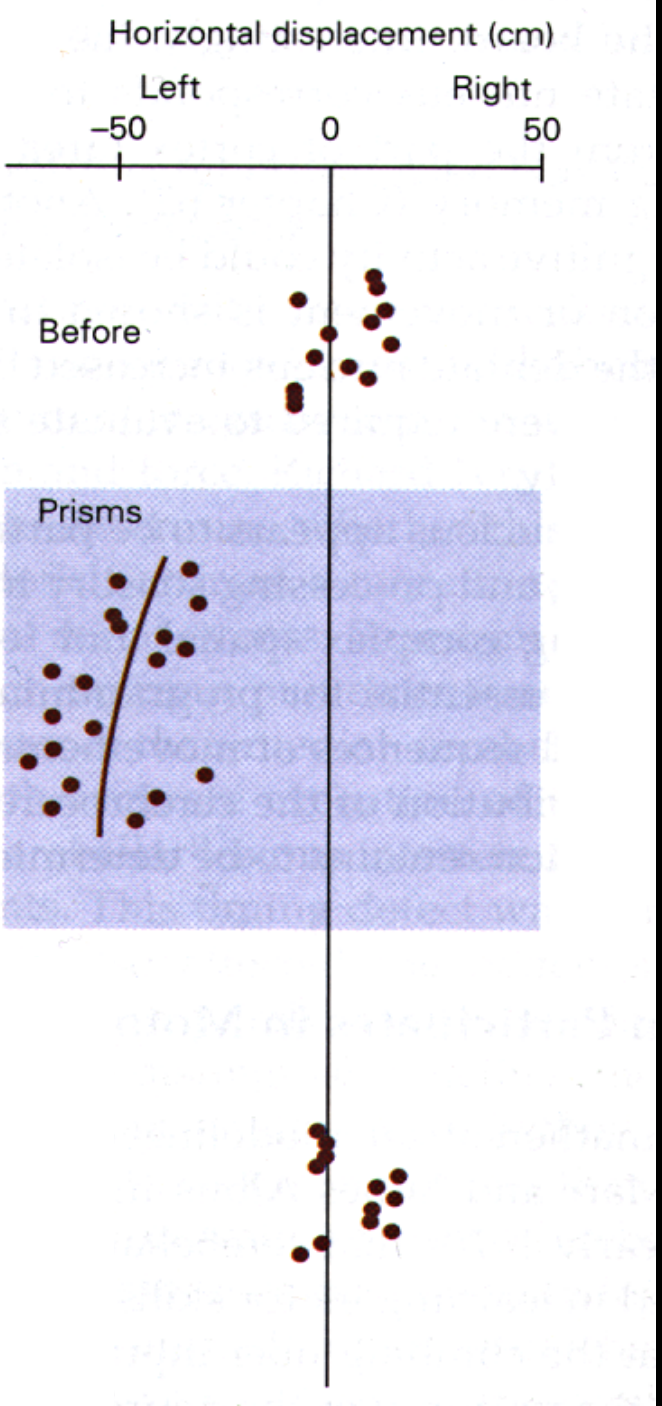
Coordination of movements

Pavlovian Classical Conditioning




Horizontal displacement (cm)
Left
Right
–50
0
50
Before
Prisms
Time
After



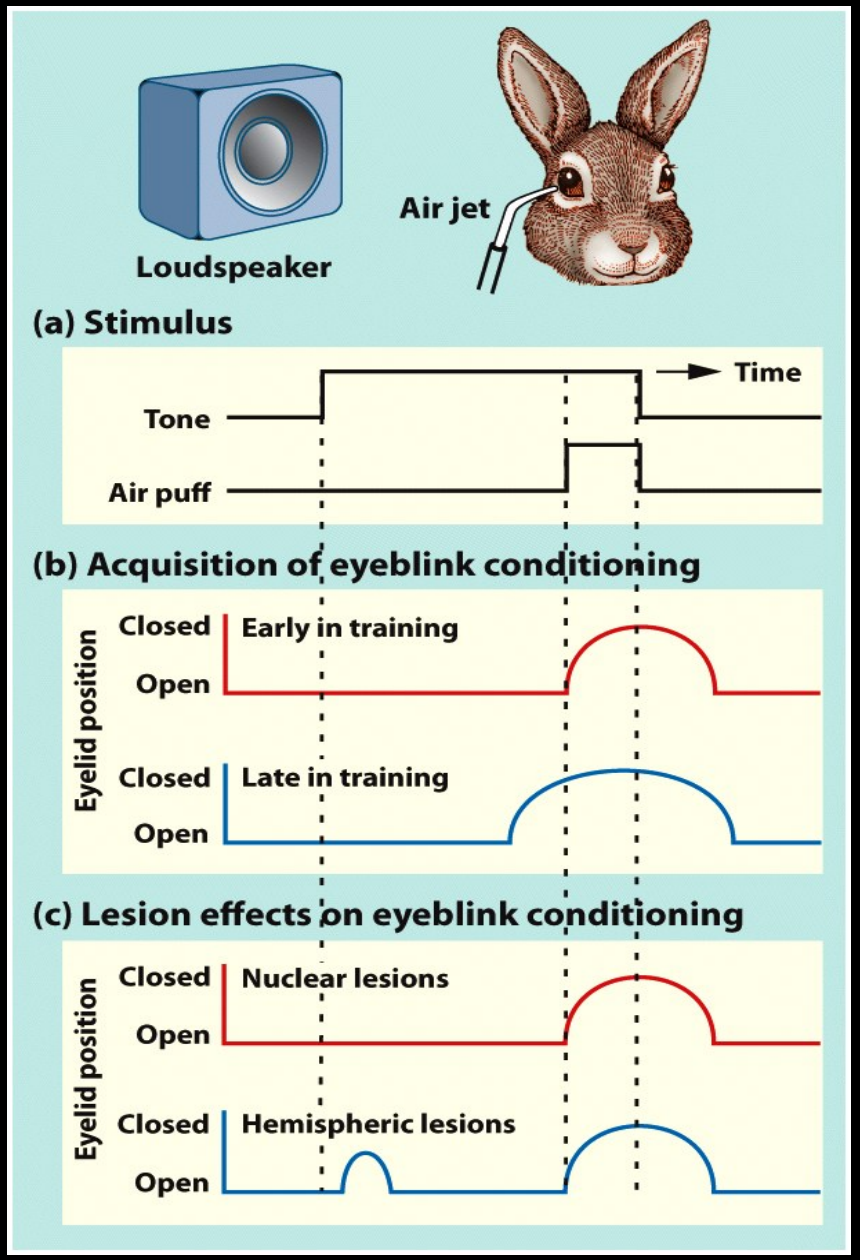

Horizontal displacement (cm)
Left
Right
–50
0
50
Before
Prisms

Cerebellum and Motor Learning

Vestibulo-ocular reflex

Coordination of movements

Pavlovian Classical Conditioning

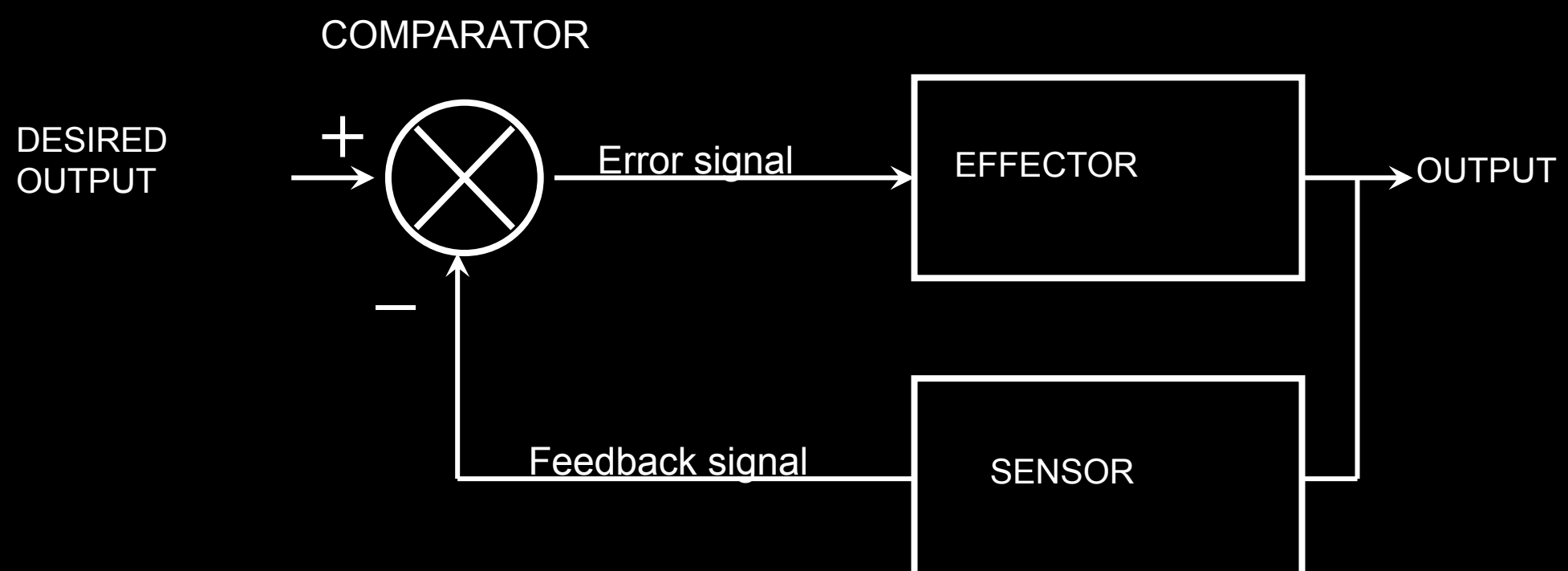

Loudspeaker
Air jet
(a) Stimulus
Time
Tone
Air puff
(b) Acquisition of eyeblink conditioning
Eyelid position
Closed
Open
Early in training
Closed
Open
Late in training
(c) Lesion effects on eyeblink conditioning
Eyelid position
Closed
Open
Nuclear lesions
Closed
Open
Hemispheric lesions

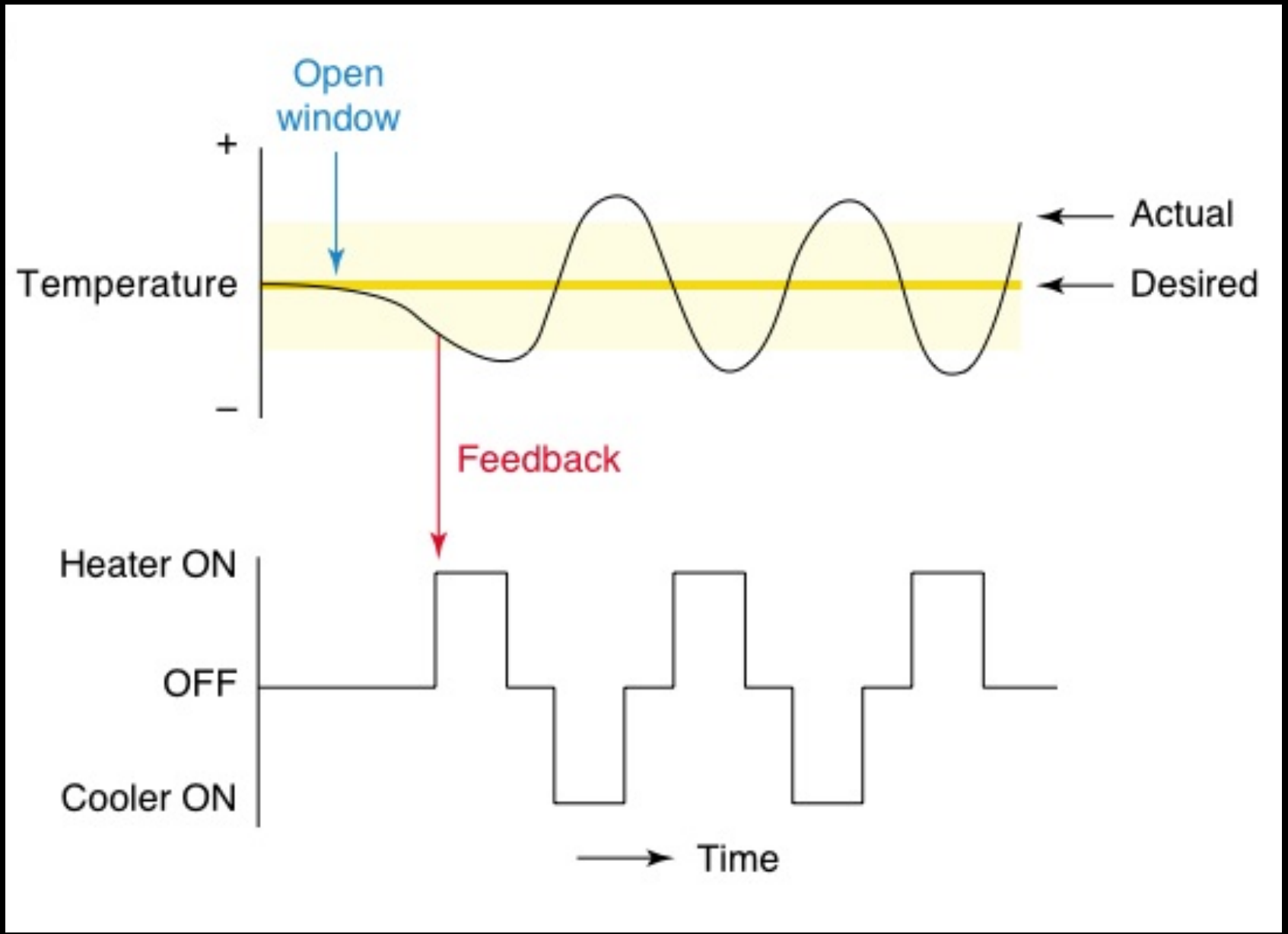
Cerebellum as a Control System

Feedback Controller for Slow movements (e.g., posture)

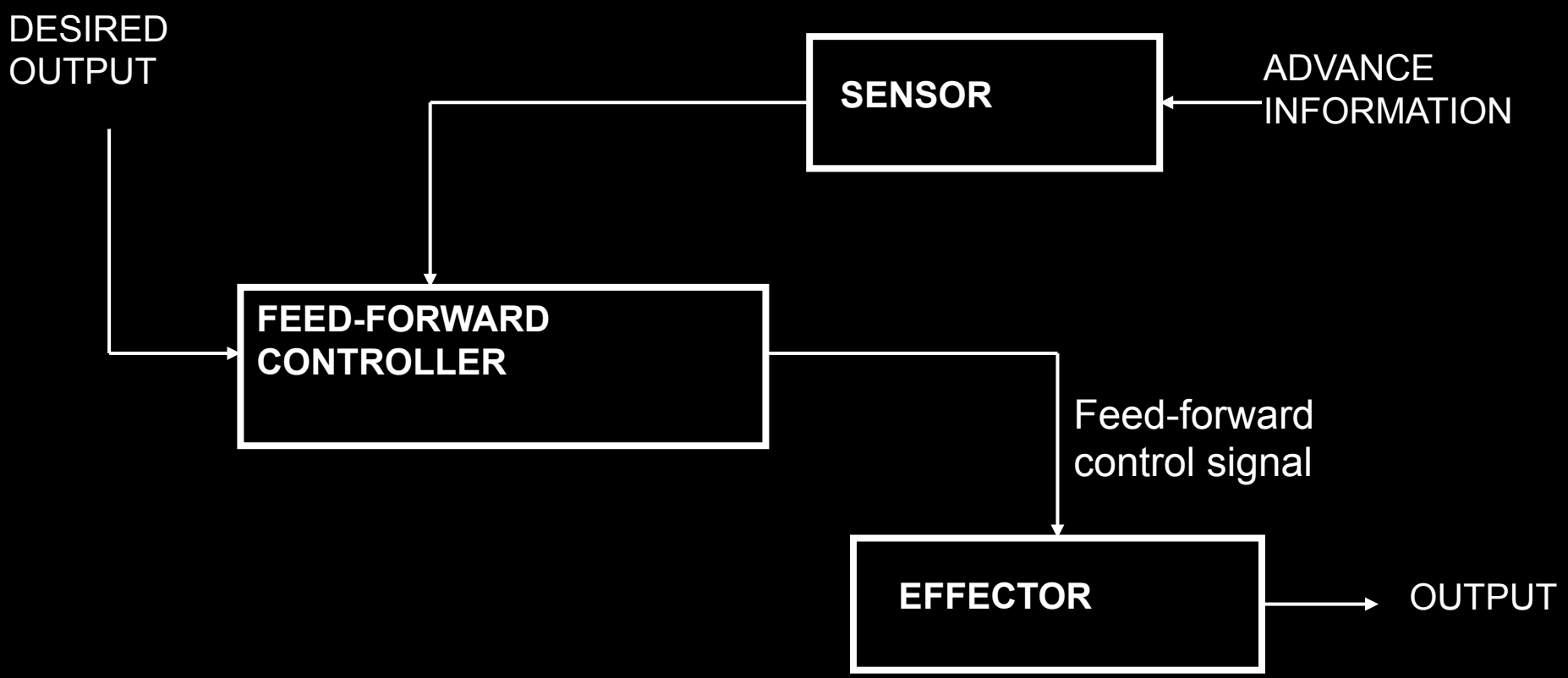
Feedforward Controller for Fast movements (e.g., most voluntary movements)

Feedback control system

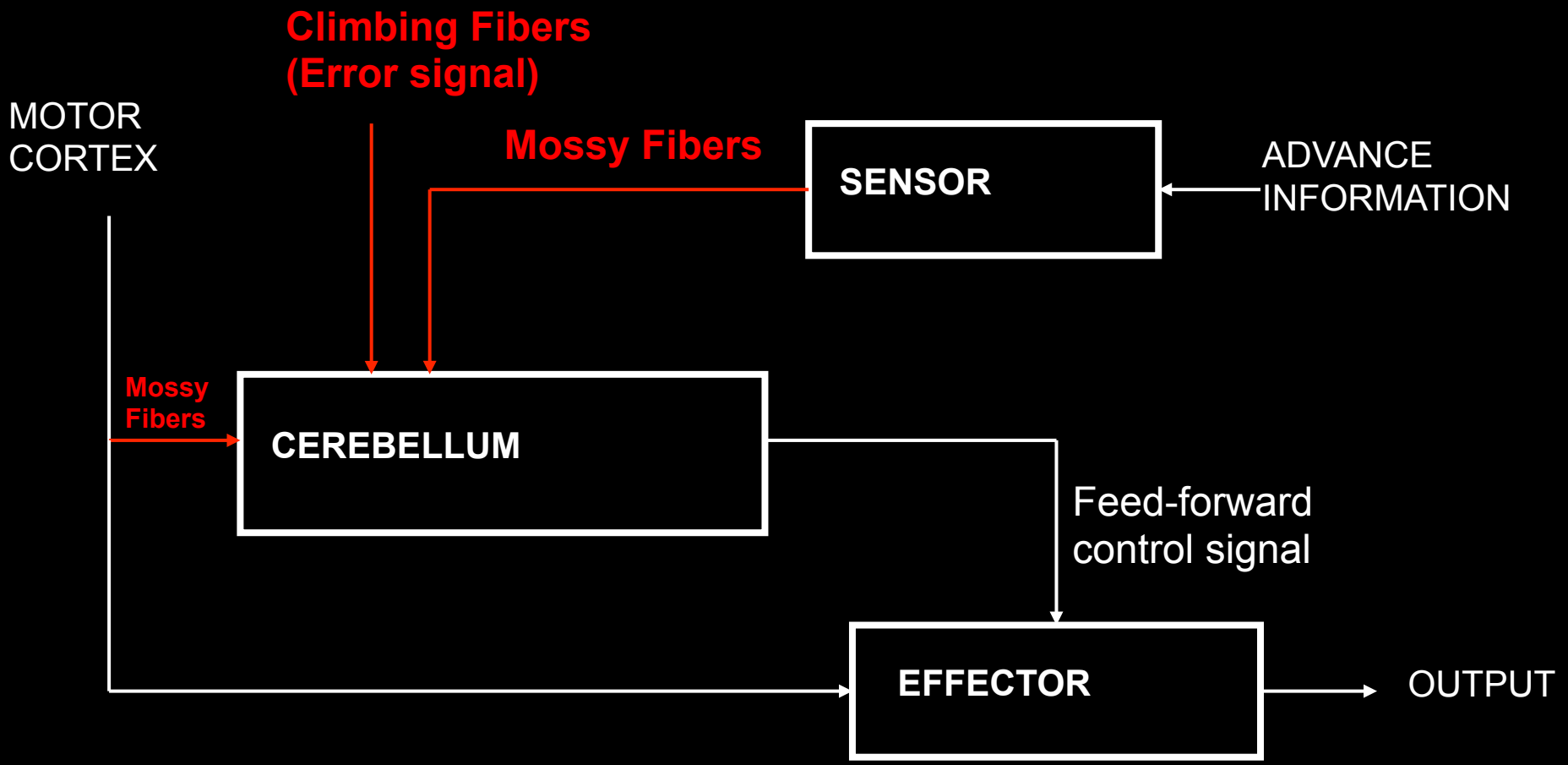



Open window
+
Temperature
–
Actual
Desired
Feedback
Heater ON
OFF
Cooler ON
Time

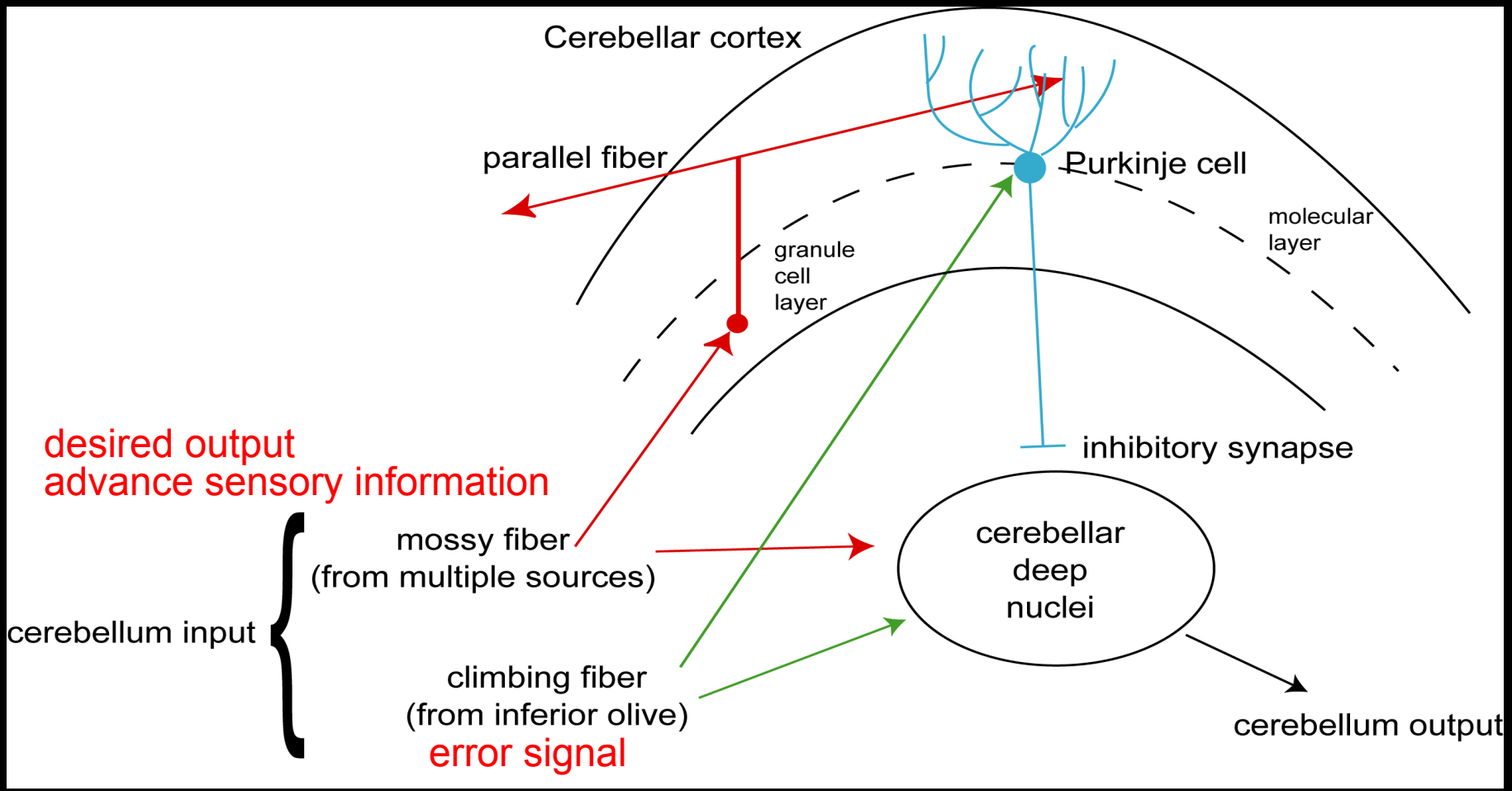
Feedforward control system



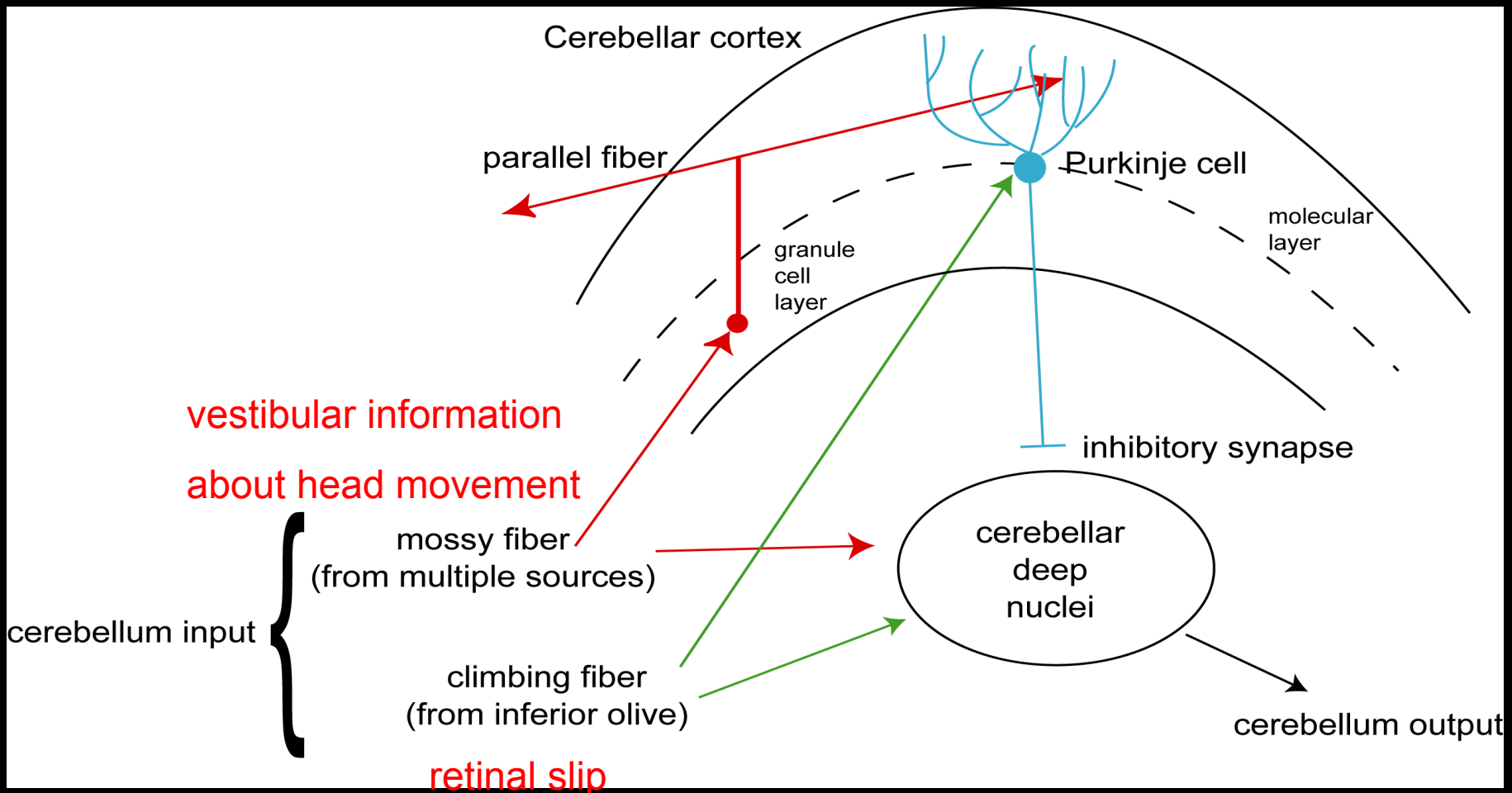
Cerebellum as a feedforward control system

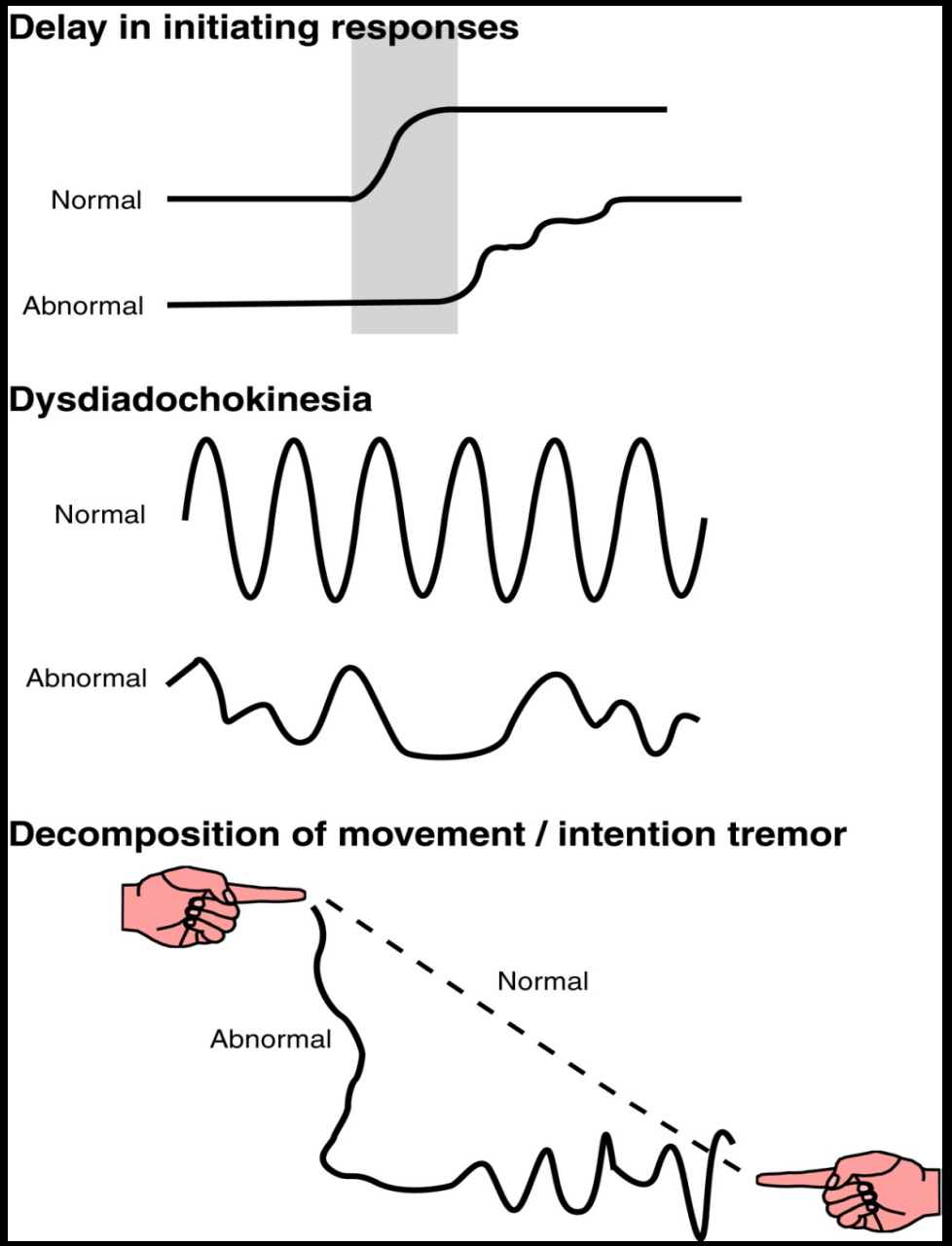


Internal Circuitry of Cerebellum



VOR and feedforward control




Delay in initiating responses
Normal
Abnormal
Dysdiadochokinesia
Normal
Abnormal
Decomposition of movement / intention tremor
Normal
Abnormal

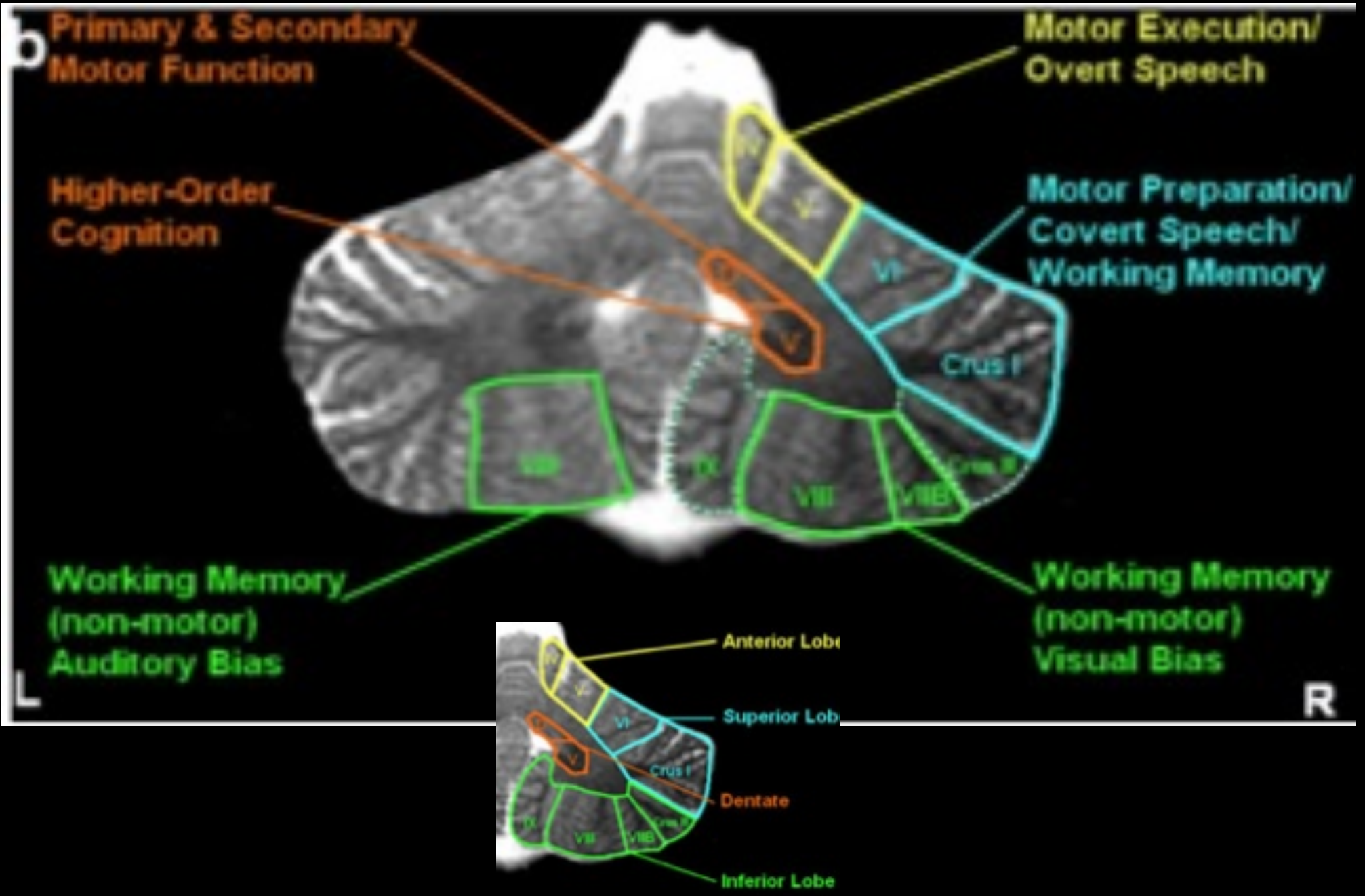
Cerebellum and Cognitive Function

Need same control system for cognitive "*movements*" e.g. making a sandwich—what to do first, in what order
(removal of cerebellar tumor, inability to make a sandwich)
Restricted verbal fluency
Unpredictable social interactions—link to autism
Problems with verbal working memory
***But* not as severe as damage to cortical area**

Cerebellum and Cognitive Function

Anterior (lobes I to V): damage results in a motor syndrome

Posterior (lobes VII through X): damage does not result in a motor syndrome, but in cognitive deficits


b
Primary & Secondary
Motor Function
Motor Execution/
Overt Speech
Higher-Order
Cognition
Motor Preparation/
Covert Speech/
Working Memory
Crus I
VIII
VIIB
Working Memory
(non-motor)
Auditory Bias
Working Memory
(non-motor)
Visual Bias
L
R
Anterior Lobe
Superior Lobe
Crus I
Dentate
Inferior Lobe

Cerebellum as feed forward controller

Cerebellum plays a crucial role in motor coordination by acting as a feedforward controller, allowing the organism to learn through trial and error what exact pattern and sequence of motor commands is necessary to produce rapid, accurate, and effortless movements