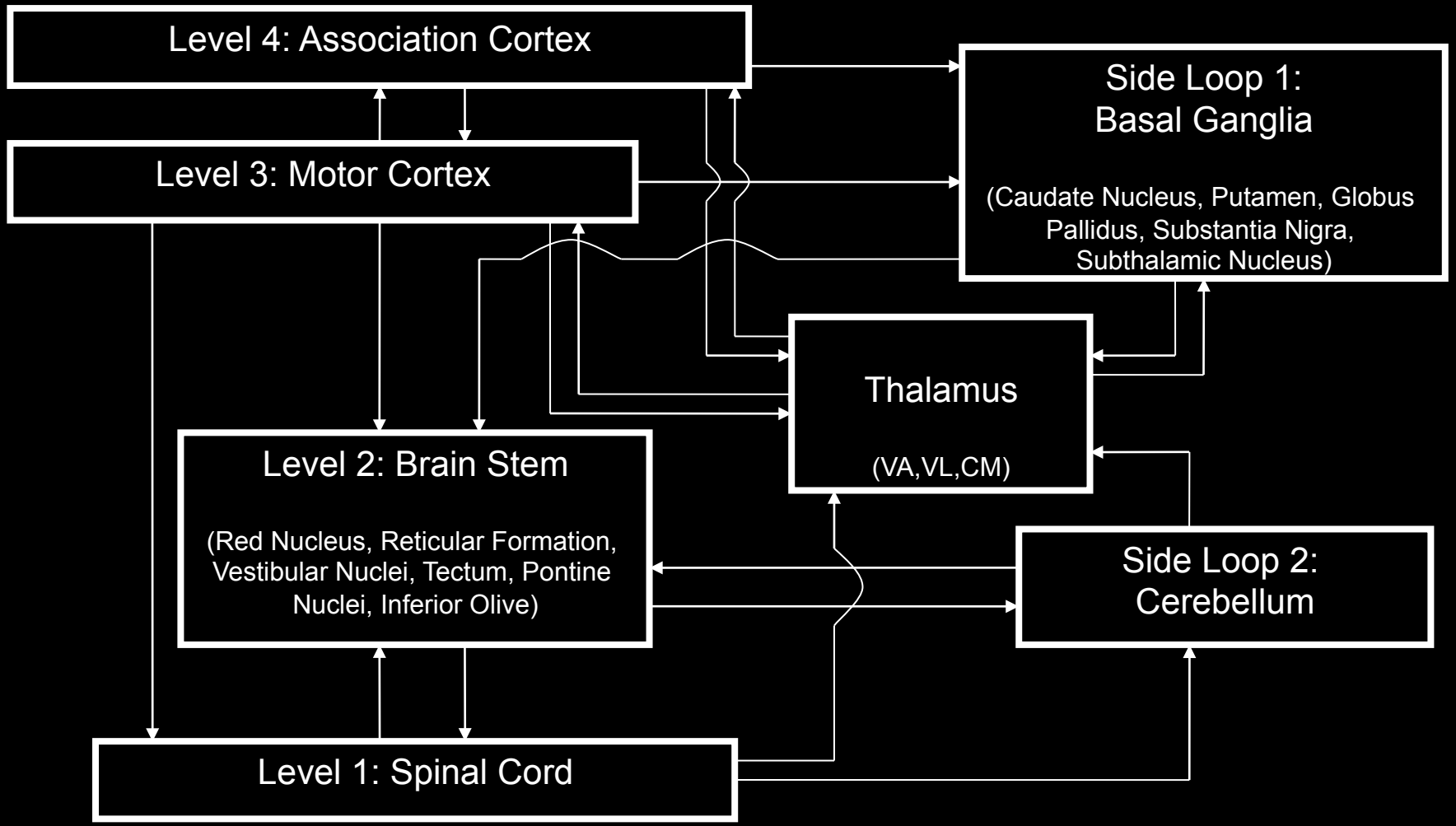
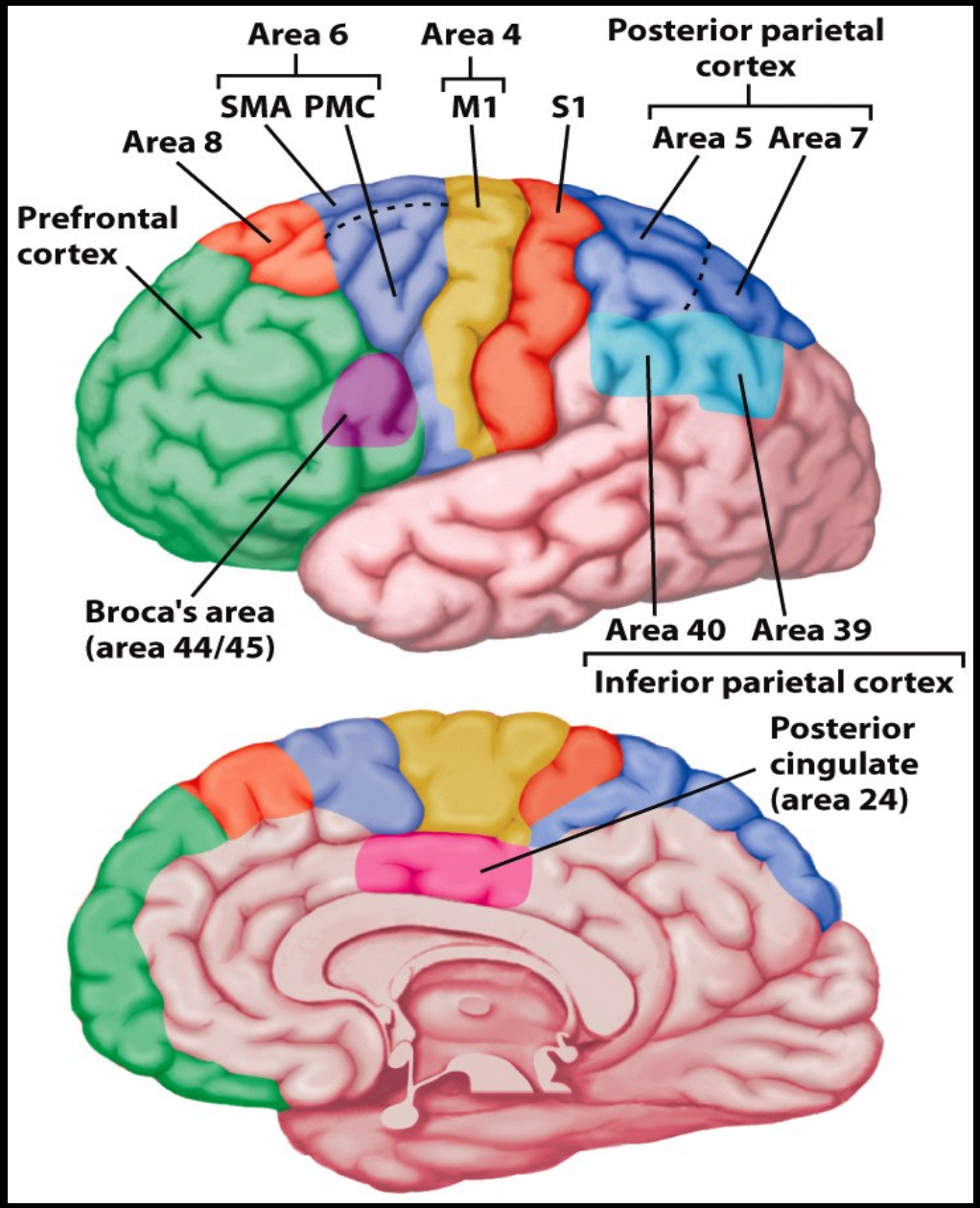
Motor Systems: Lecture 5, Motor Cortex

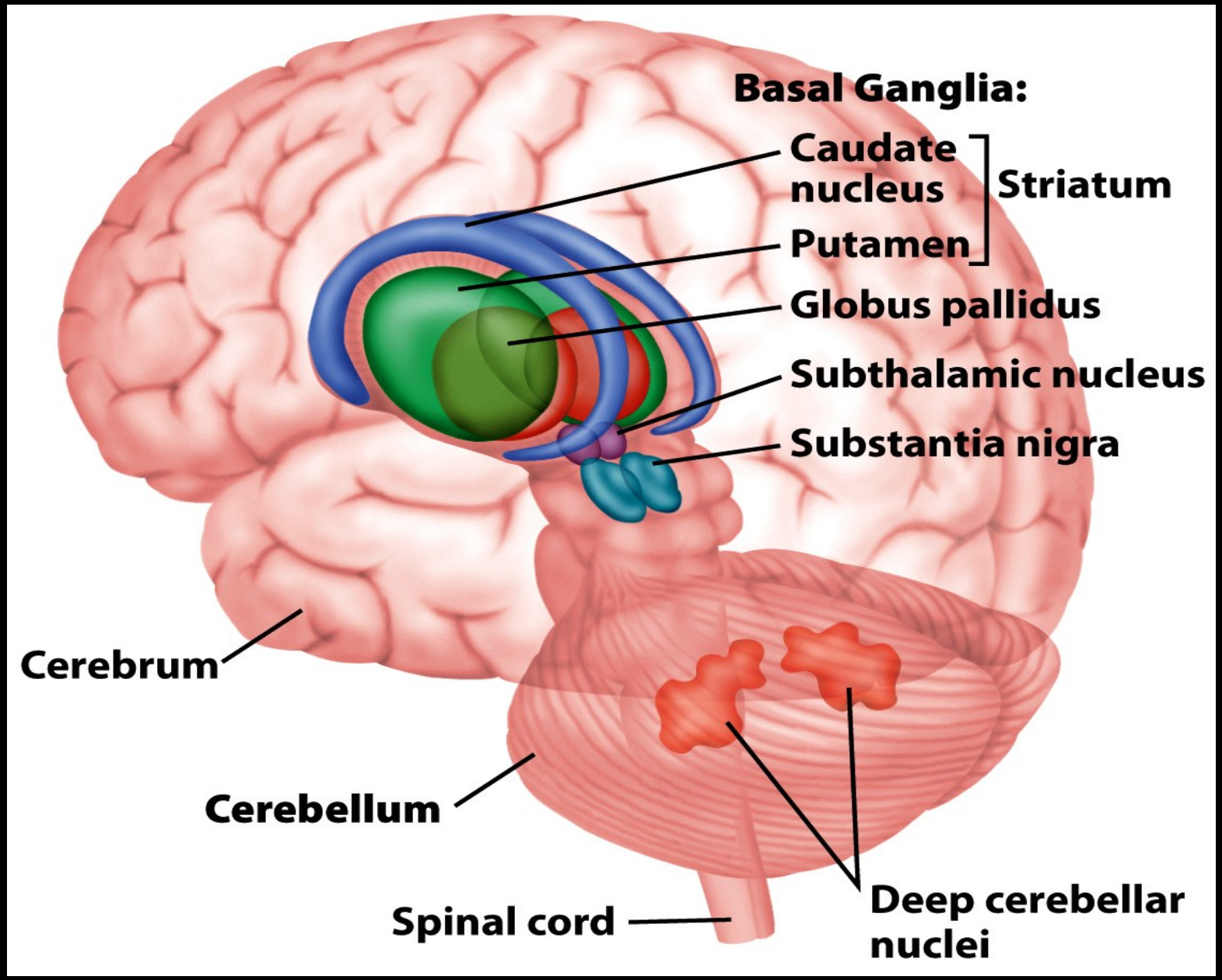
Michael S. Beauchamp, Ph.D.
Assistant Professor
Department of Neurobiology and Anatomy
University of Texas Health Science Center at Houston
Houston, TX

Michael.S.Beauchamp@uth.tmc.edu

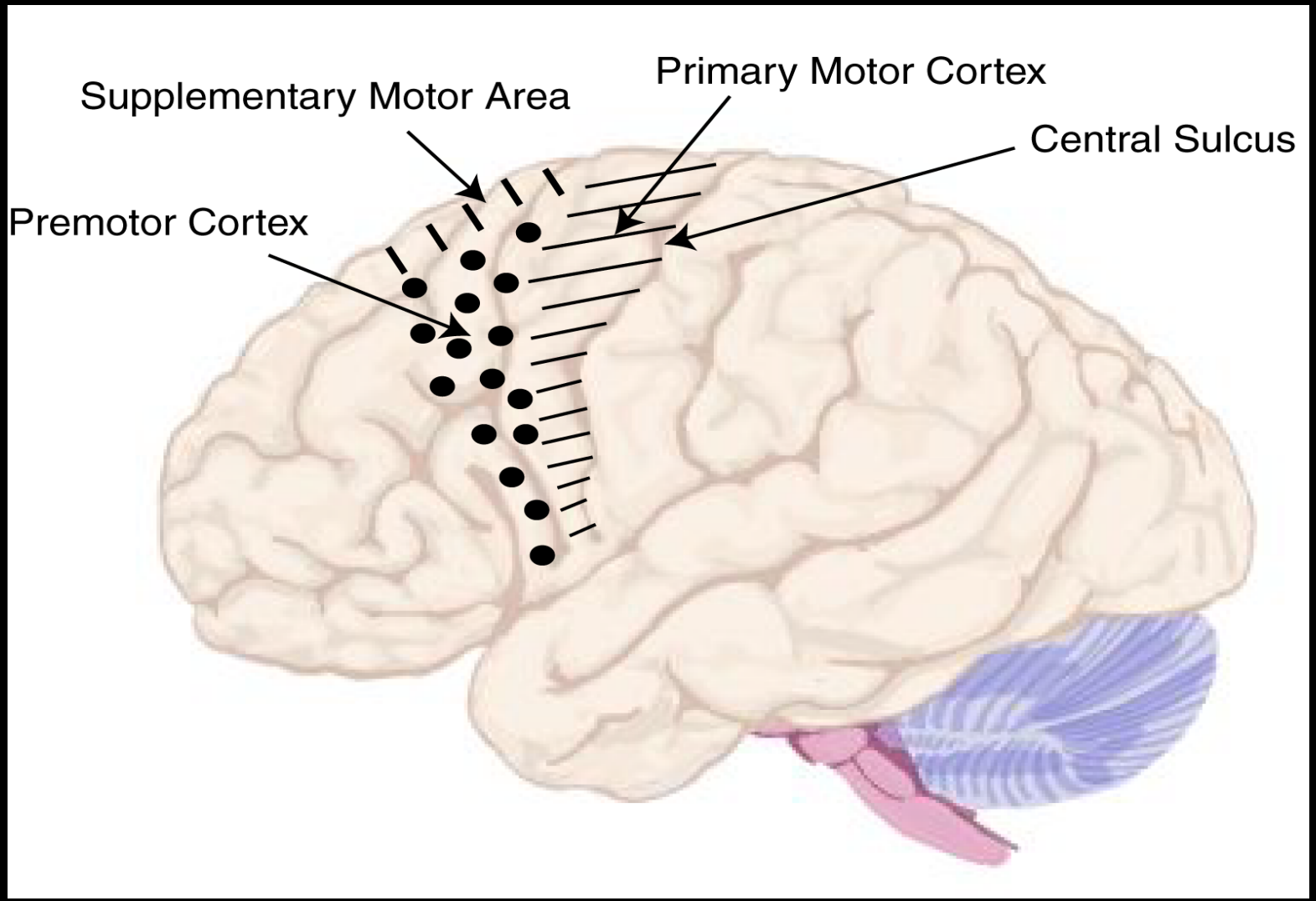
Hierarchical Organization and Functional Segregation of Central Motor Structures



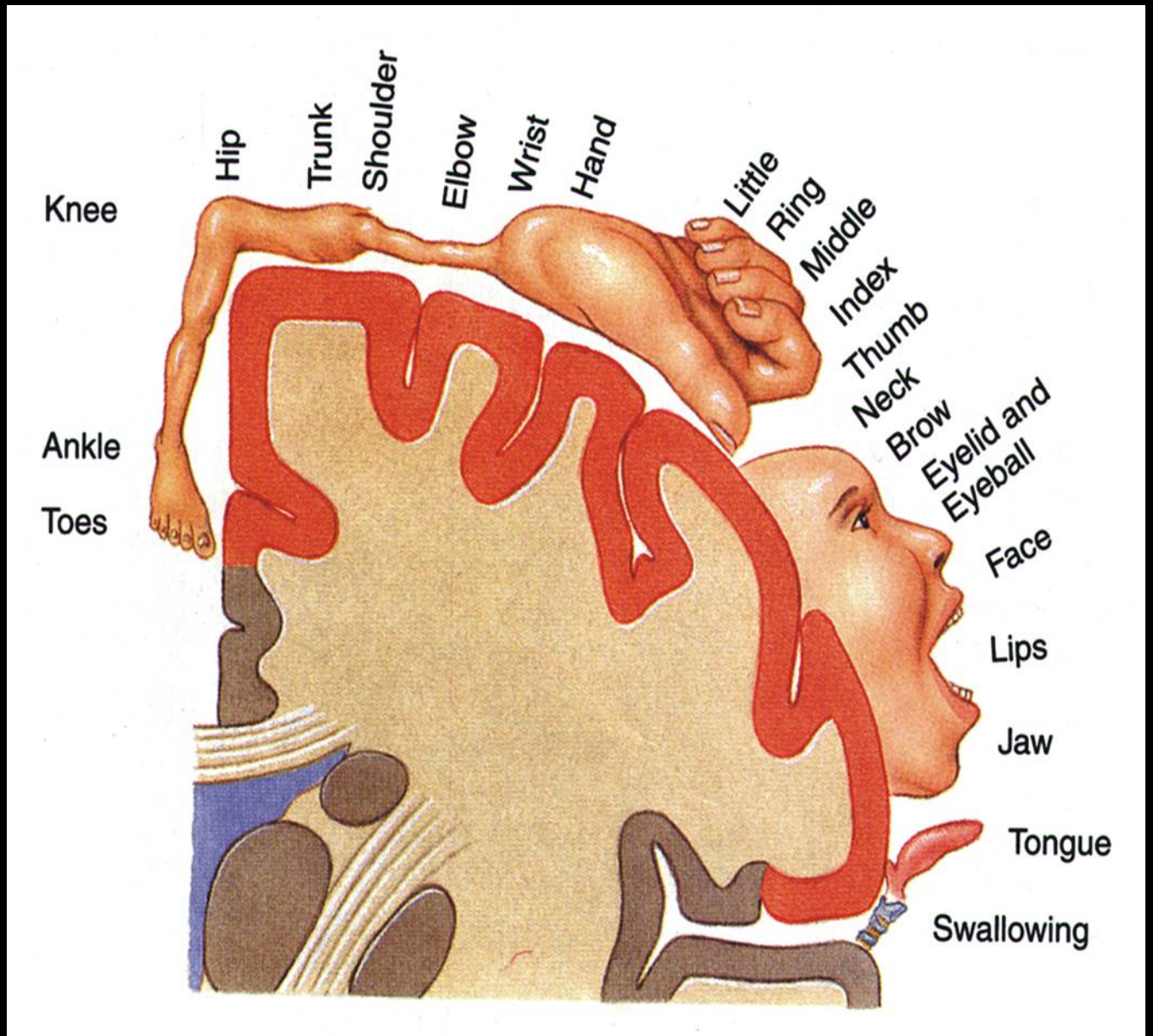

Area 6
Area 4
Posterior parietal cortex
SMA
PMC
M1
S1
Area 5
Area 7
Area 8
Prefrontal cortex
Broca's area (area 44/45)
Area 40
Area 39
Inferior parietal cortex
Posterior cingulate (area 24)


Basal Ganglia:
Caudate nucleus
Striatum
Putamen
Globus pallidus
Subthalamic nucleus
Substantia nigra
Cerebrum
Cerebellum
Spinal cord
Deep cerebellar nuclei

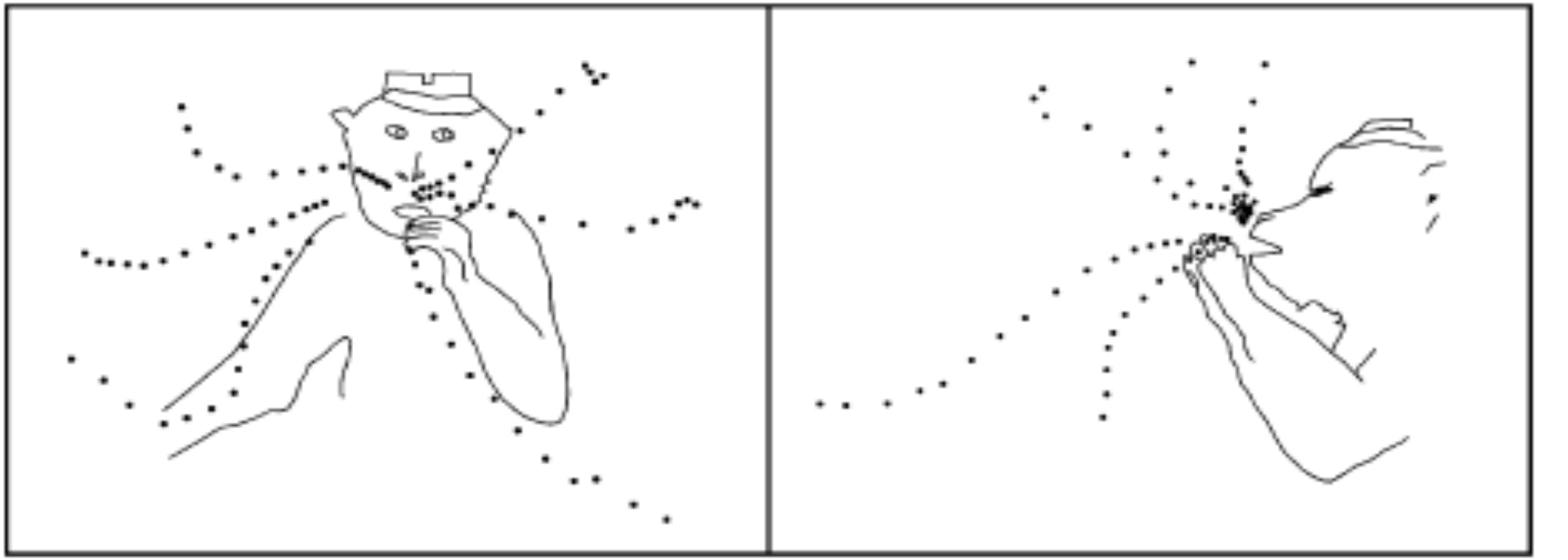
Motor Cortex



Motor Homunculus

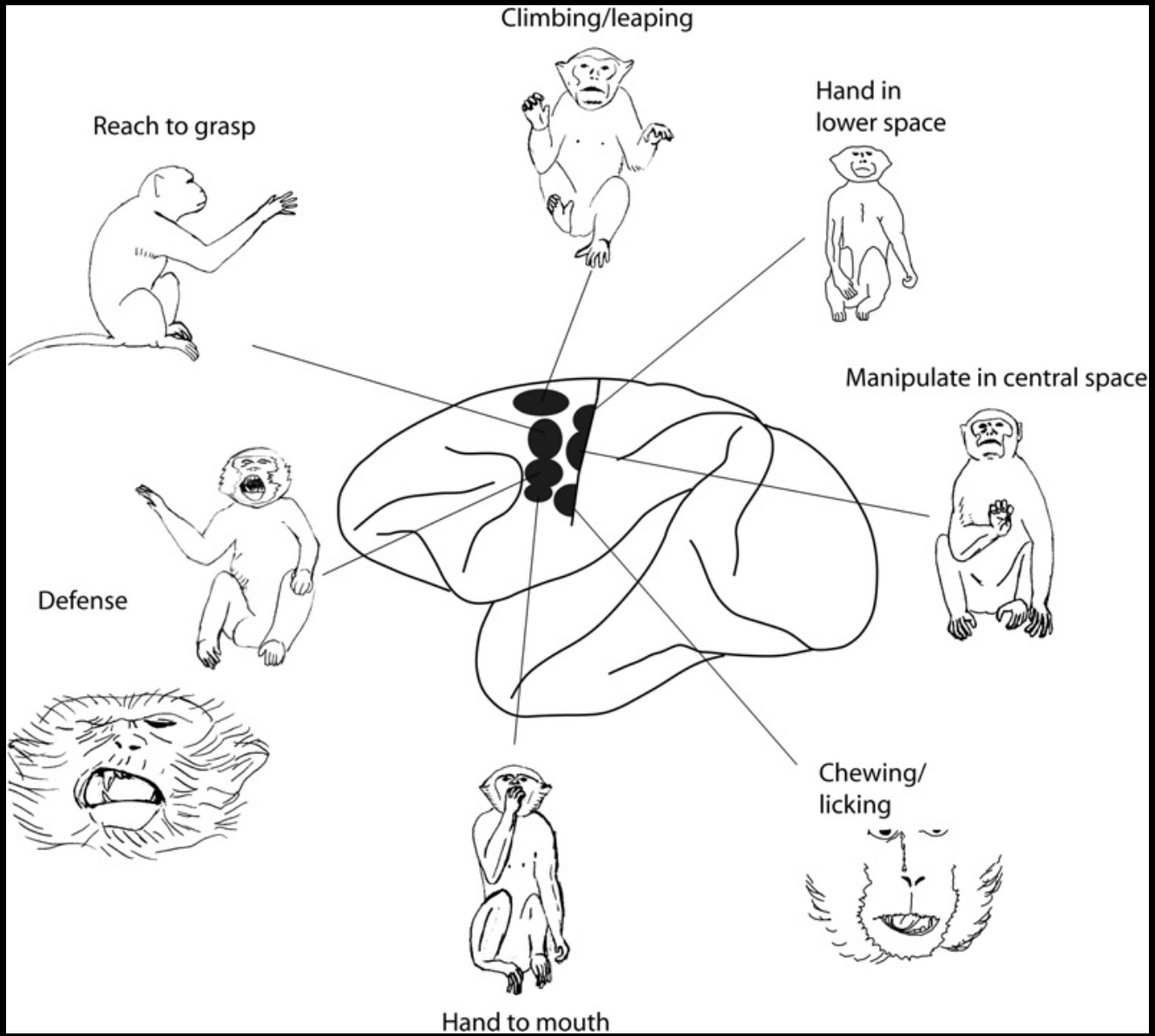


Long stimulation (e.g., 500 msec) of motor cortex elicits stereotyped postures



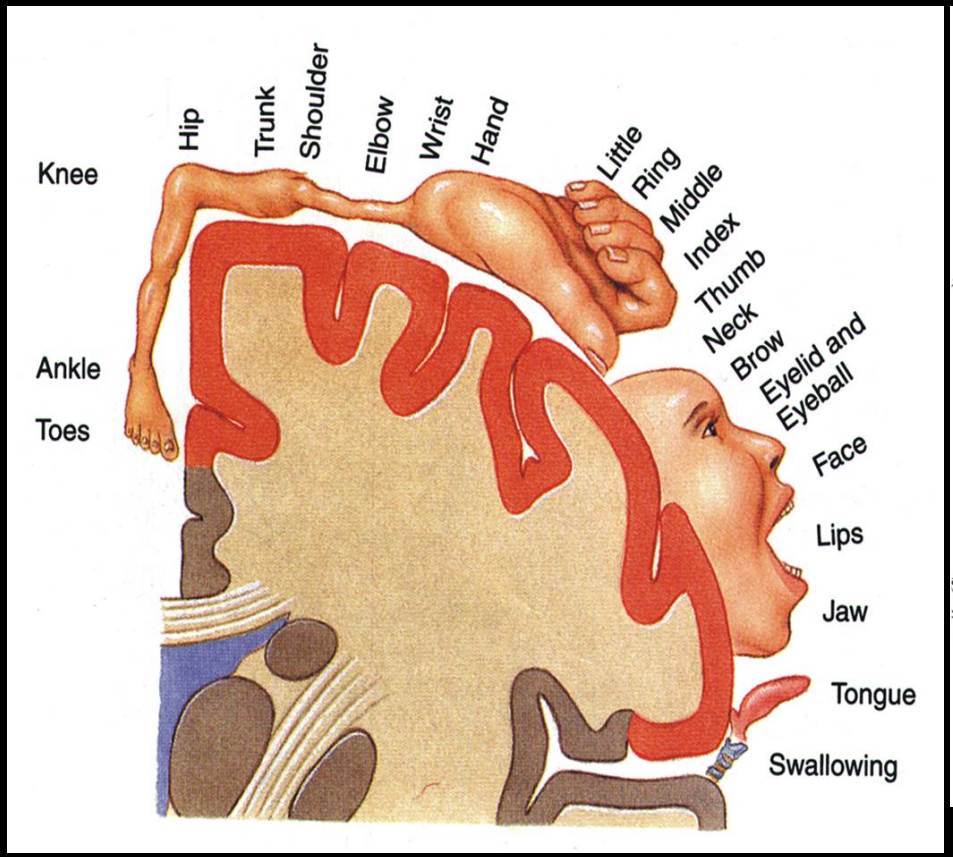
Graziano et al.,
Neuron, 2002 34:841-51.

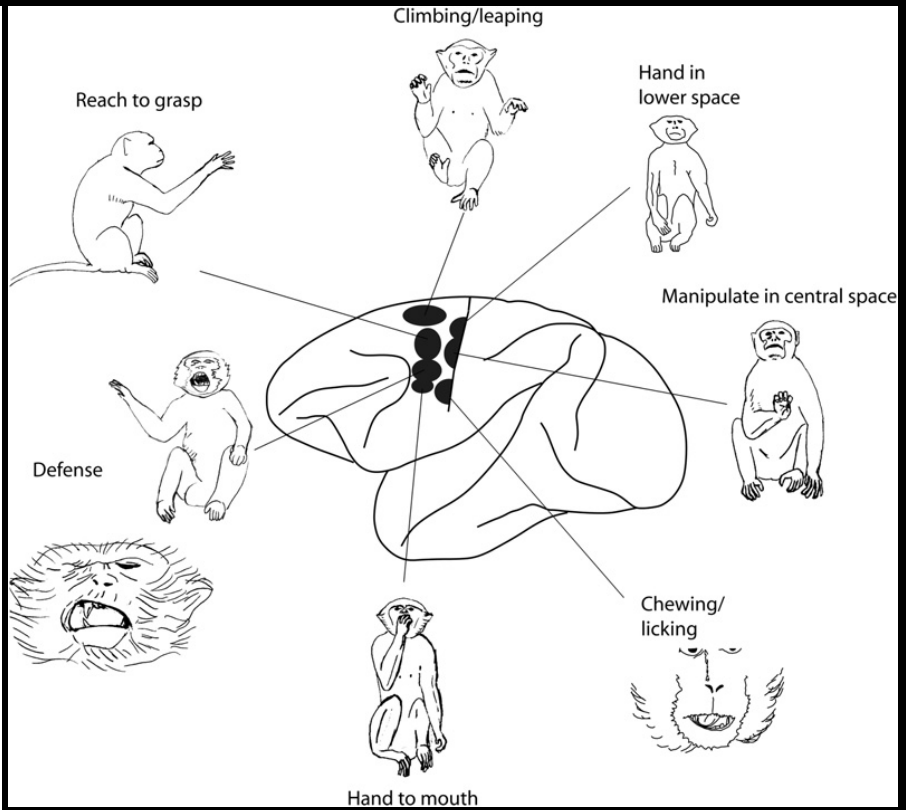
Action Zones

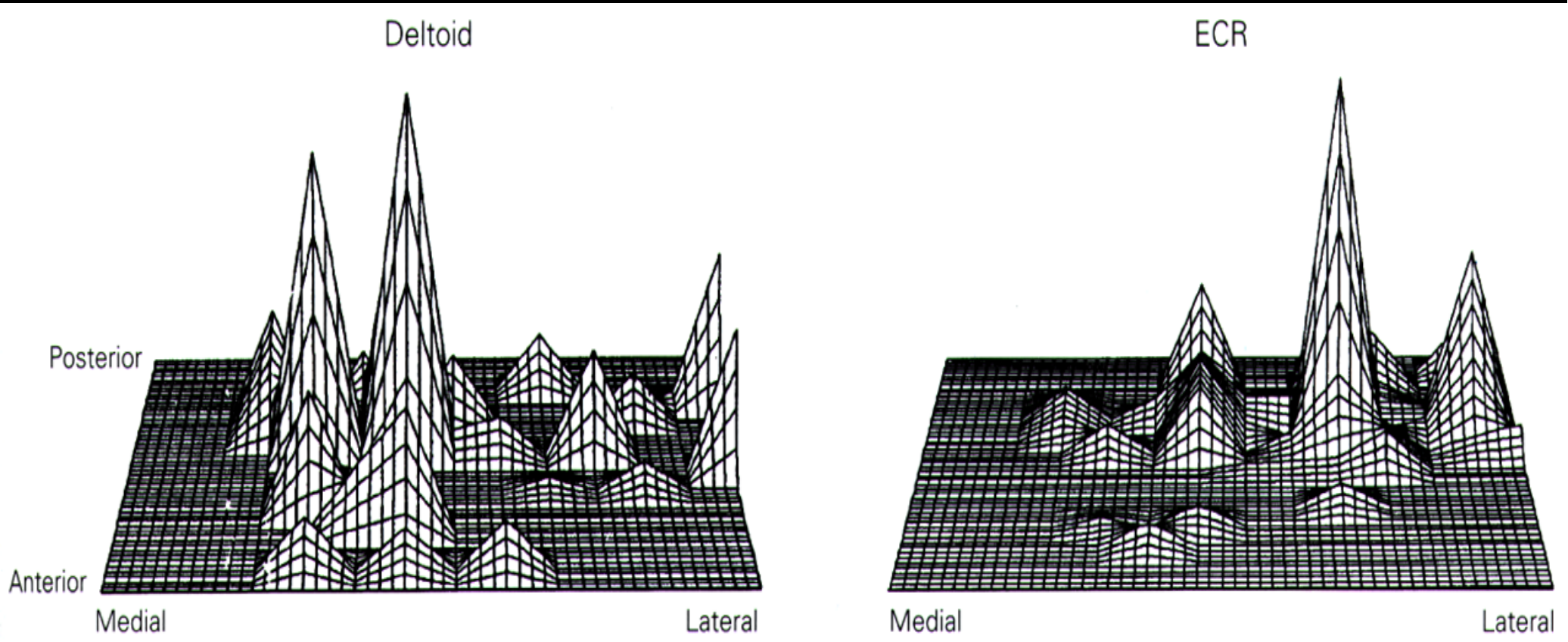


Aflalo & Graziano,
Neuron, 2007

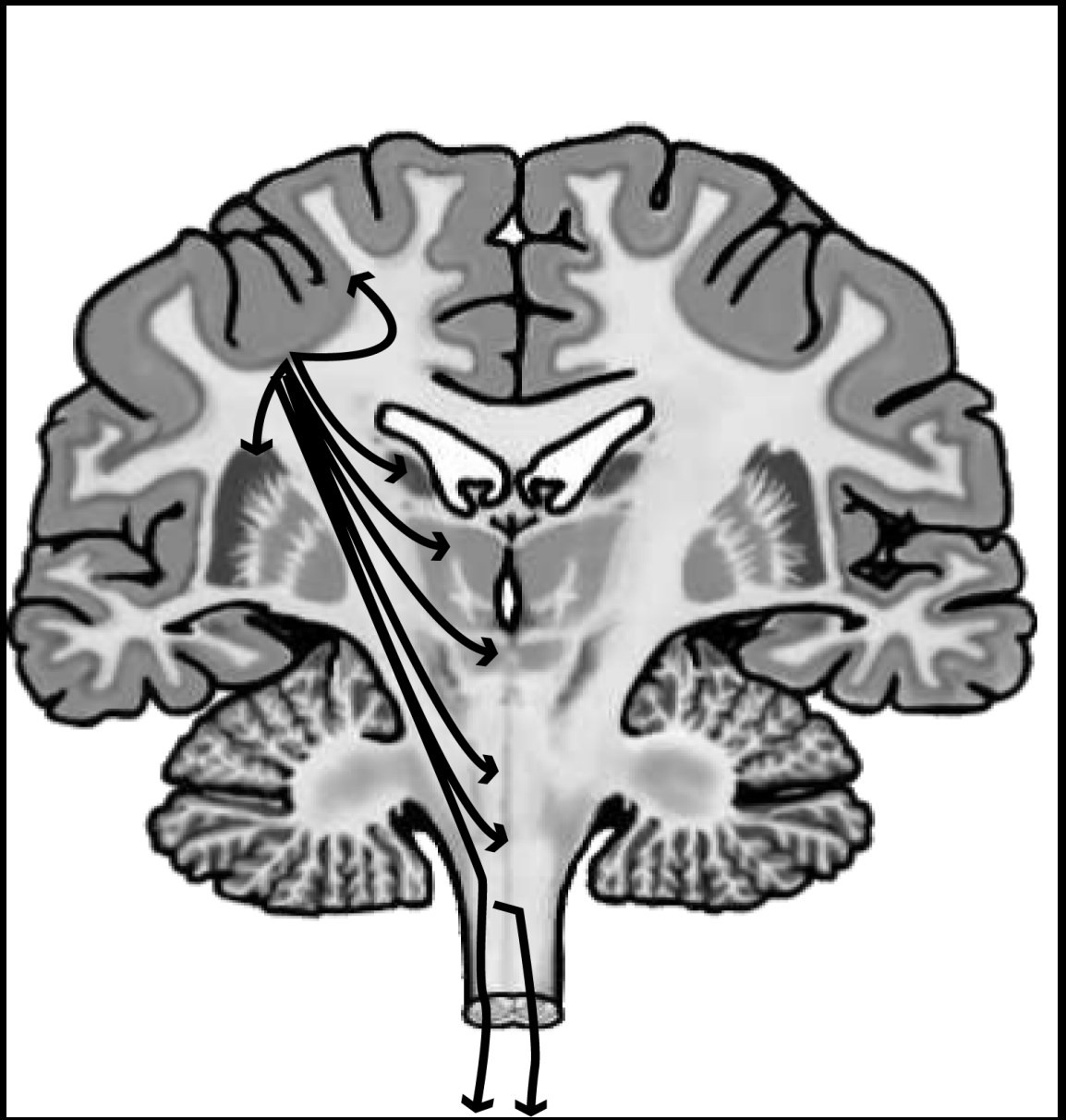
Motor Homunculus vs. Action Zones

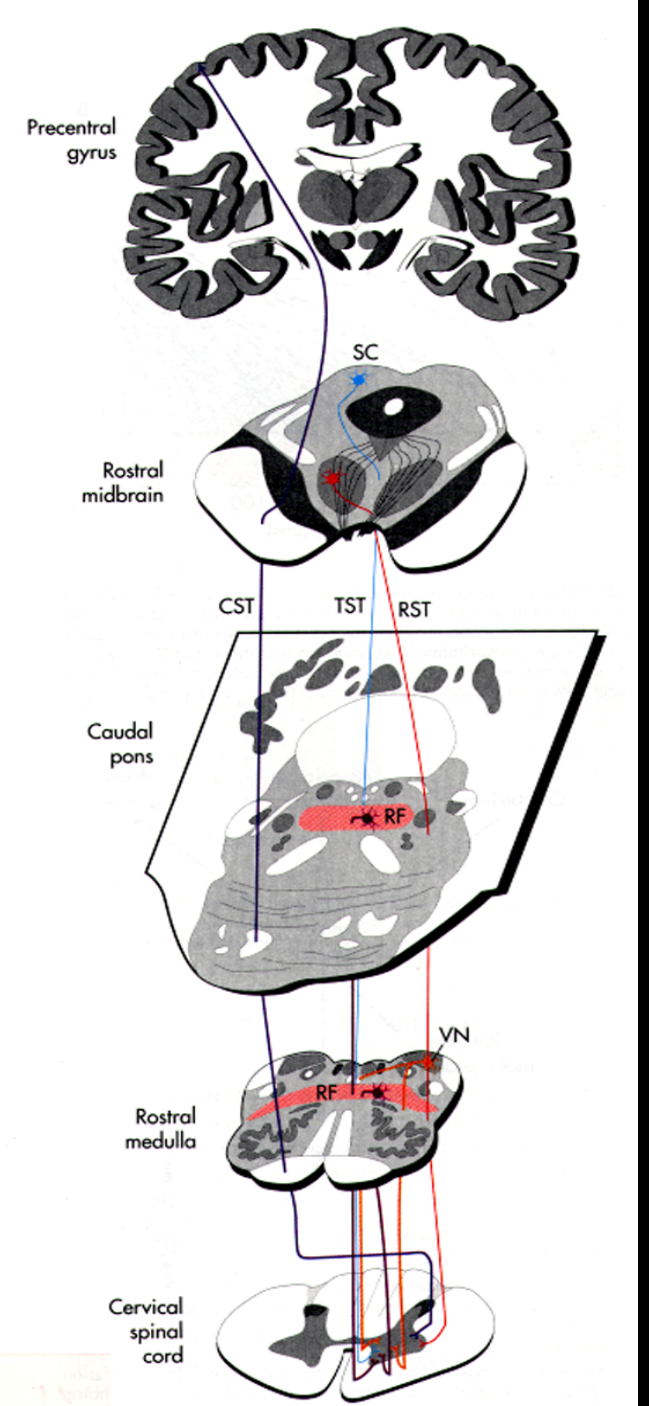


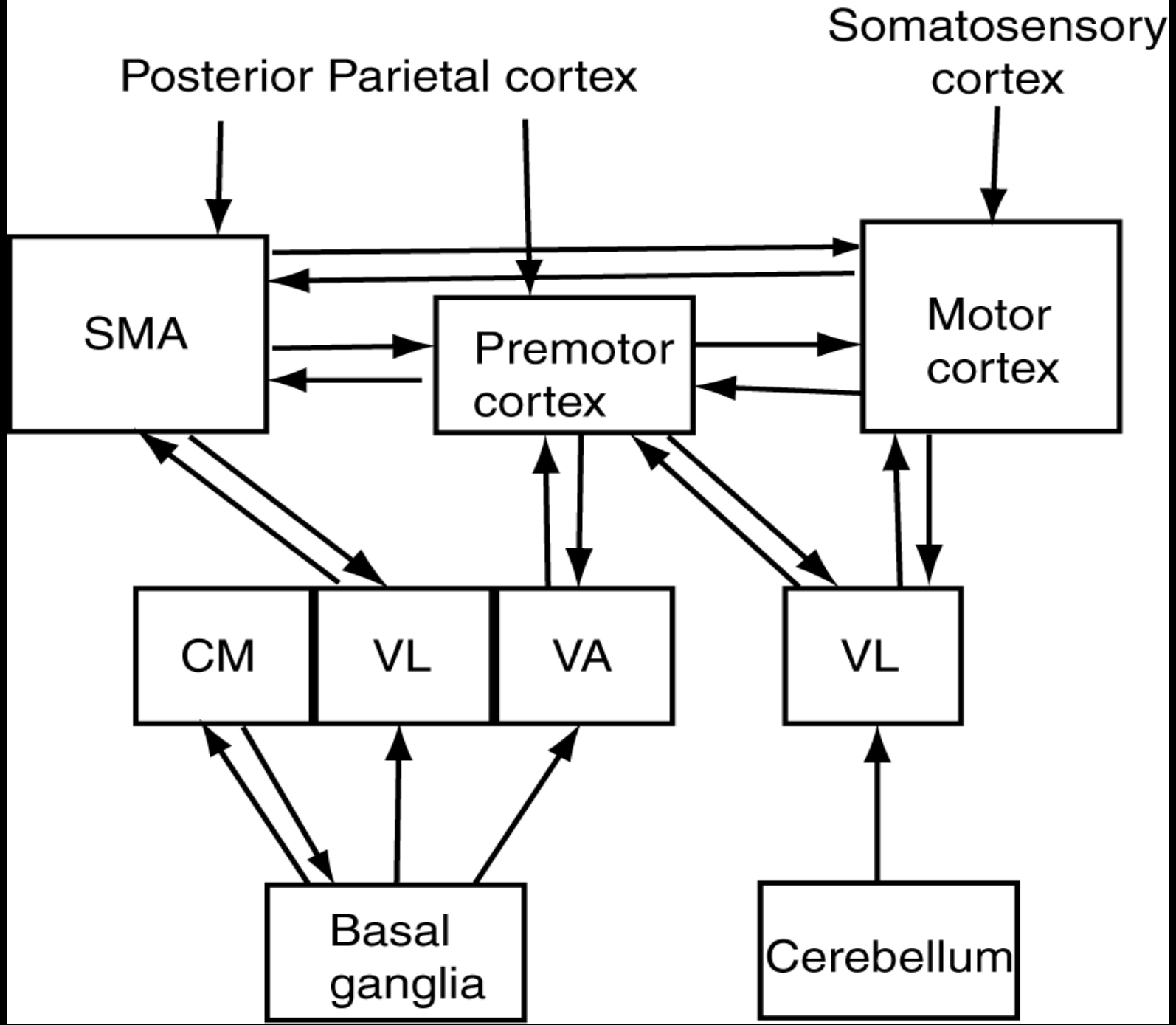




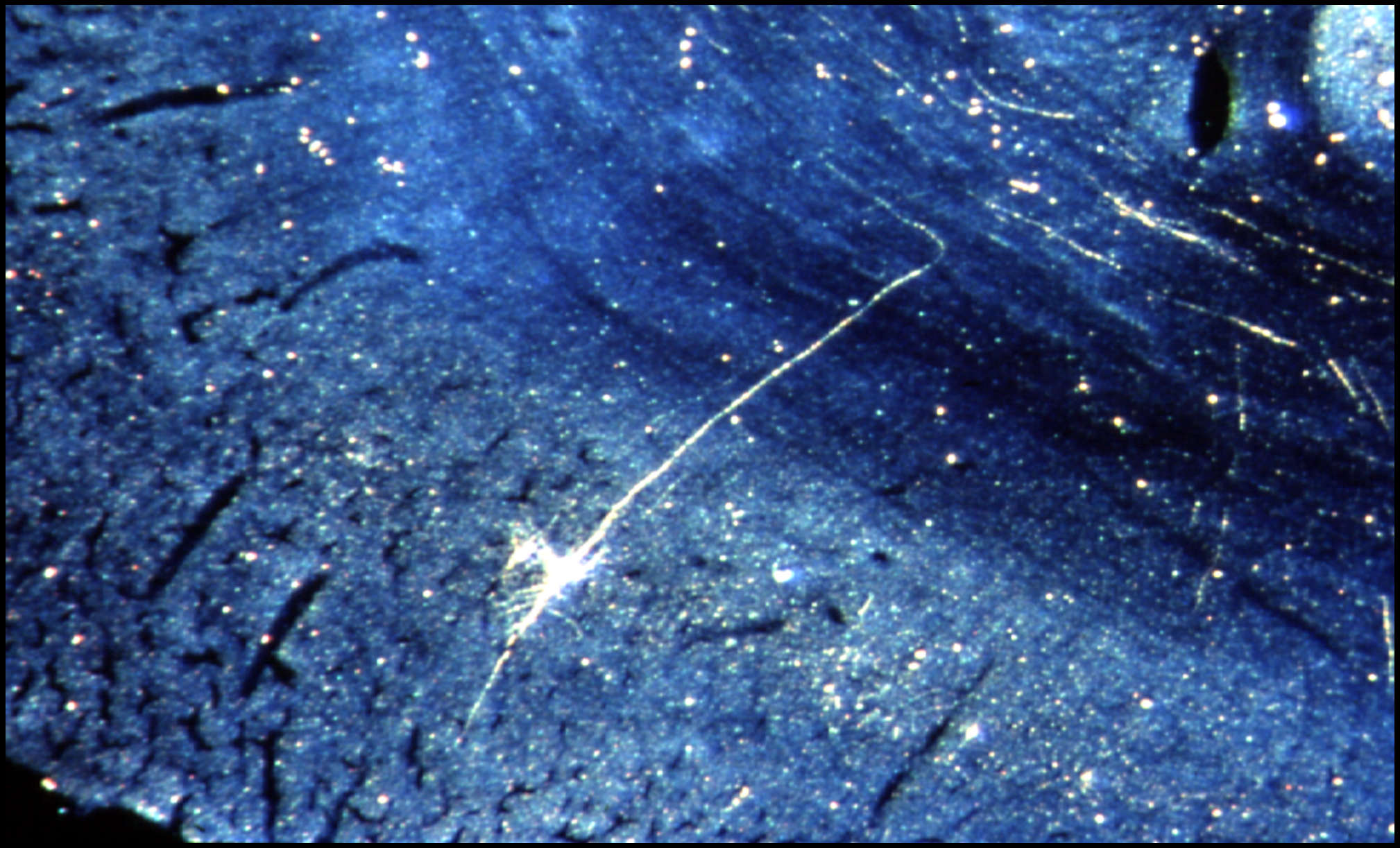
From J. Krakauer & C. Ghez (2000), in *Principles of Neural Science, 4th Edition* (Kandel, Schwartz, & Jessel, Eds.)

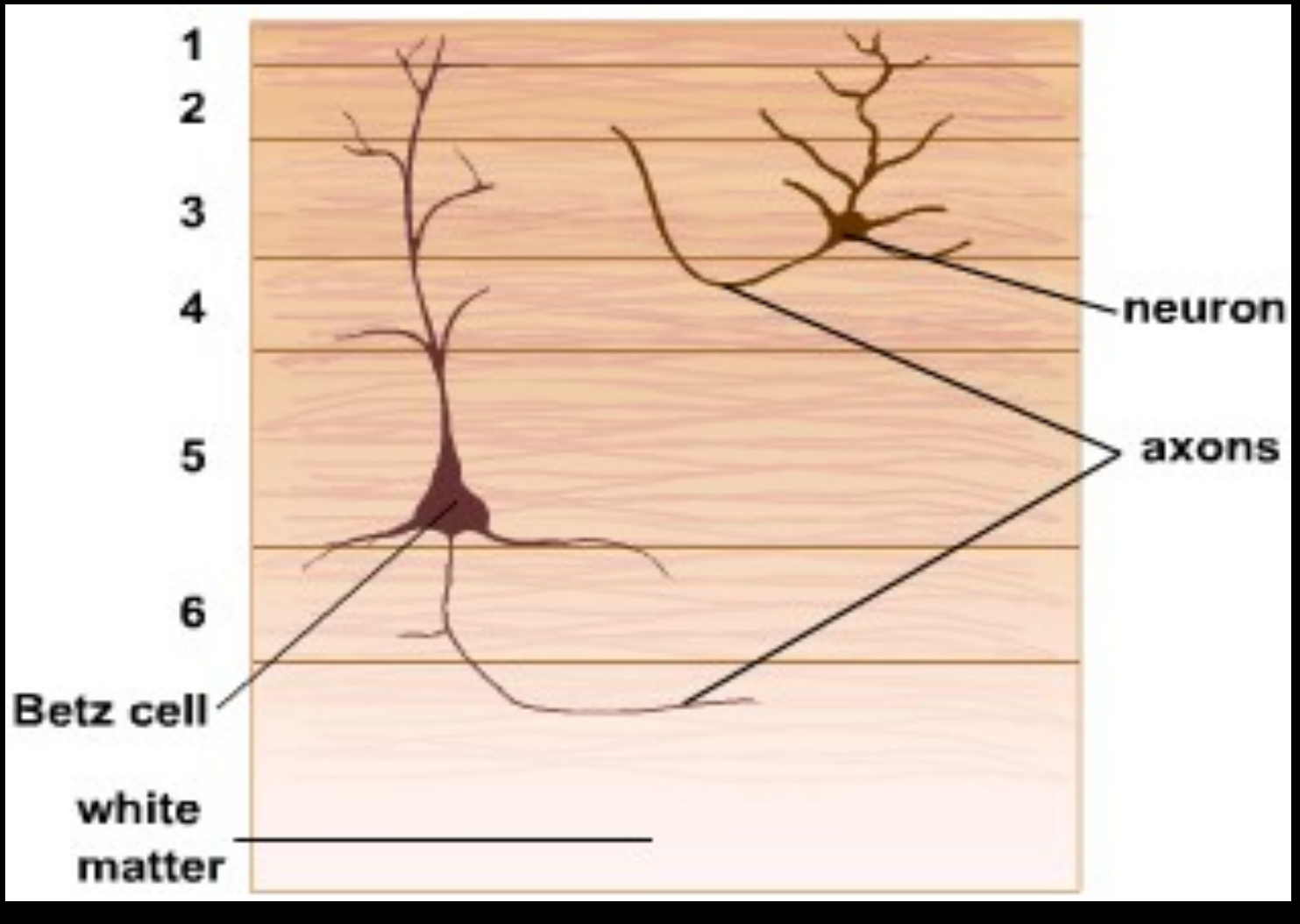



Precentral gyrus
SC
Rostral midbrain
CST
TST
RST
Caudal pons
RF
VN
RF
Rostral medulla
Cervical spinal cord

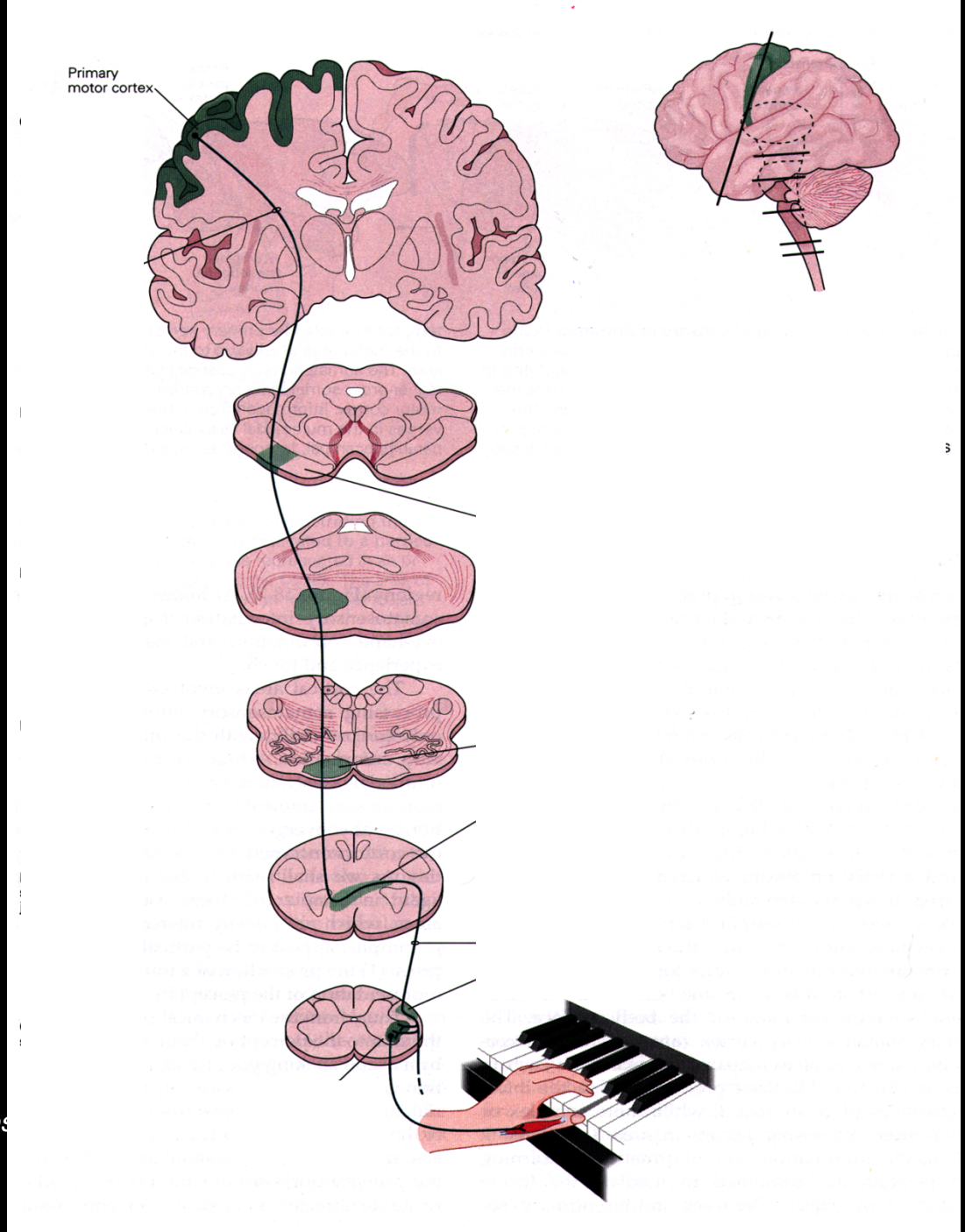

Posterior Parietal cortex
Somatosensory cortex
SMA
Premotor cortex
Motor cortex
Thalamic nuclei
CM
VL
VA
VL
Basal ganglia
Cerebellum

Betz Cell in Layer V of Motor Cortex




1
2
3
4
5
6
neuron
axons
Betz cell
white
matter

Primary motor cortex



From D. G. Amaral (2000), in *Principles of Neural Science, 4th Edition* (Kandel, Schwartz, & Jessel, Eds.)

Origins of the Corticospinal Tract

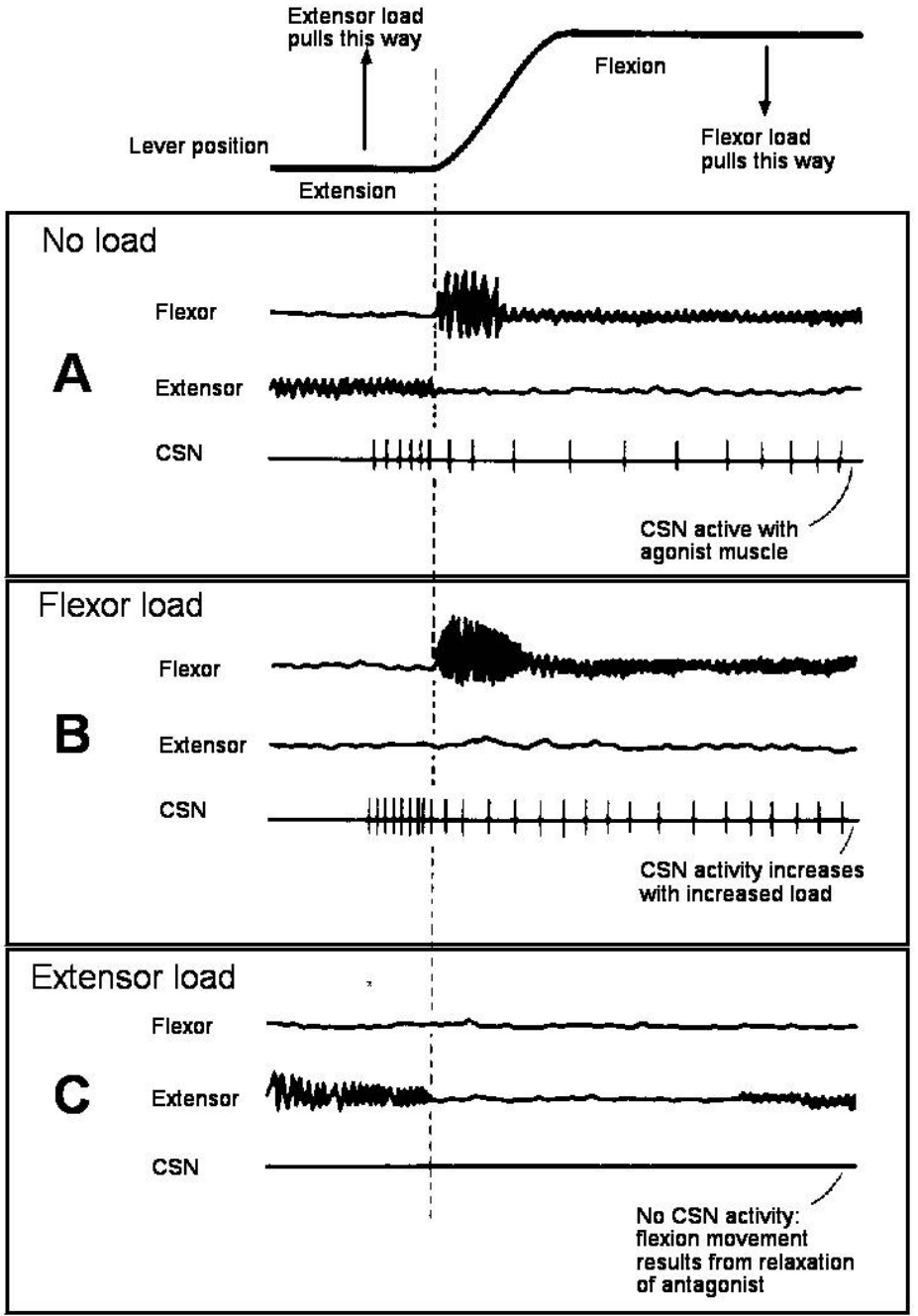
Primary Motor Cortex (~30%)
Supplementary Motor Cortex } (~30%)
Premotor Cortex
Primary Somatosensory Cortex } (~30%)
Secondary Somatosensory Cortex
Posterior Parietal Cortex (~10%)
Other minor origins

Primary Motor Cortex (M1)

Neurons fire *before* the contraction of muscle

Neurons encode *force* of contraction

Primary Motor Cortex neurons encode the **force** of movements



Evarts EV (1968) *J. Neurophysiol.* 31:14-27.

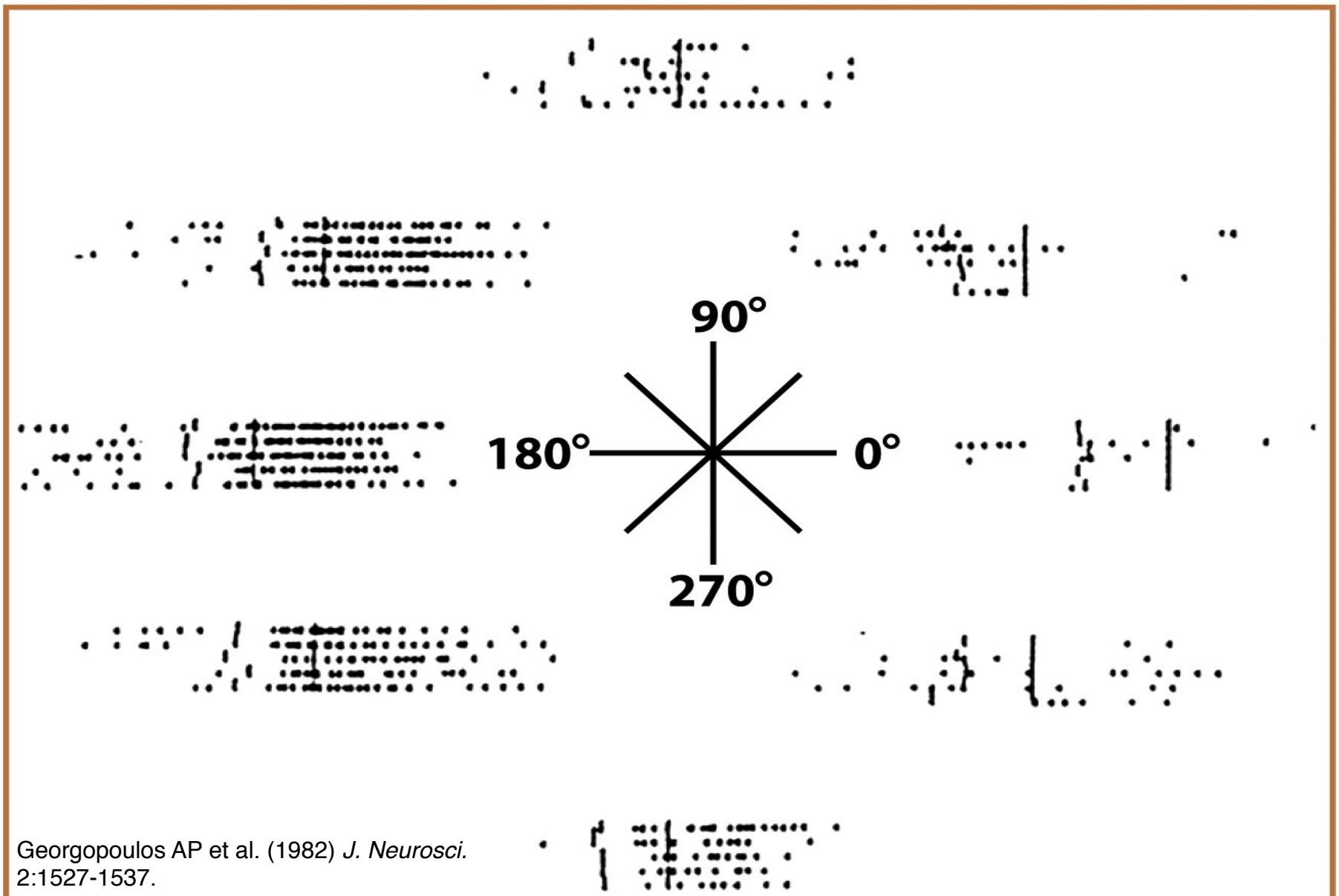
Primary Motor Cortex (M1)

Neurons fire *before* the contraction of muscle

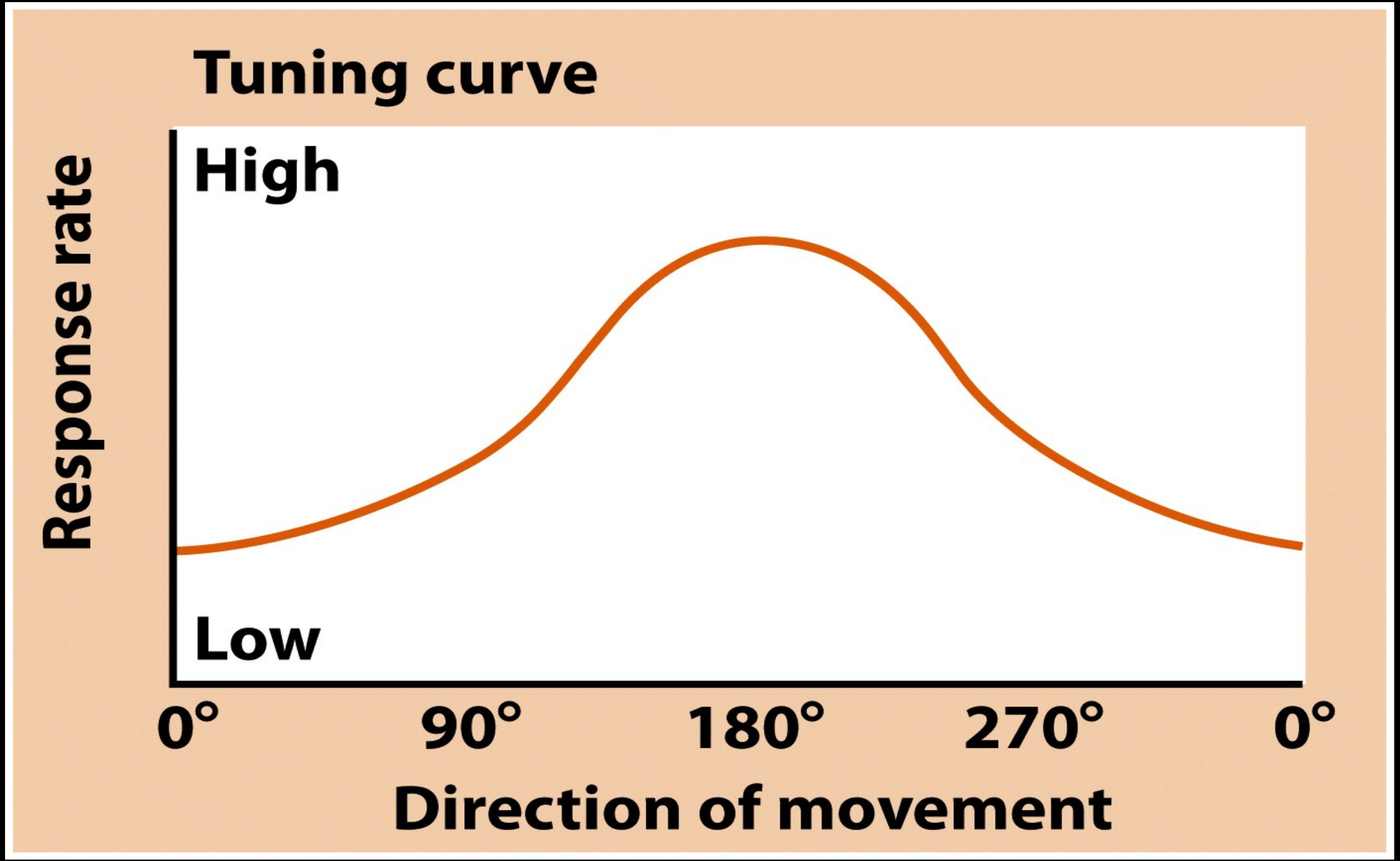
Neurons encode *force* of contraction

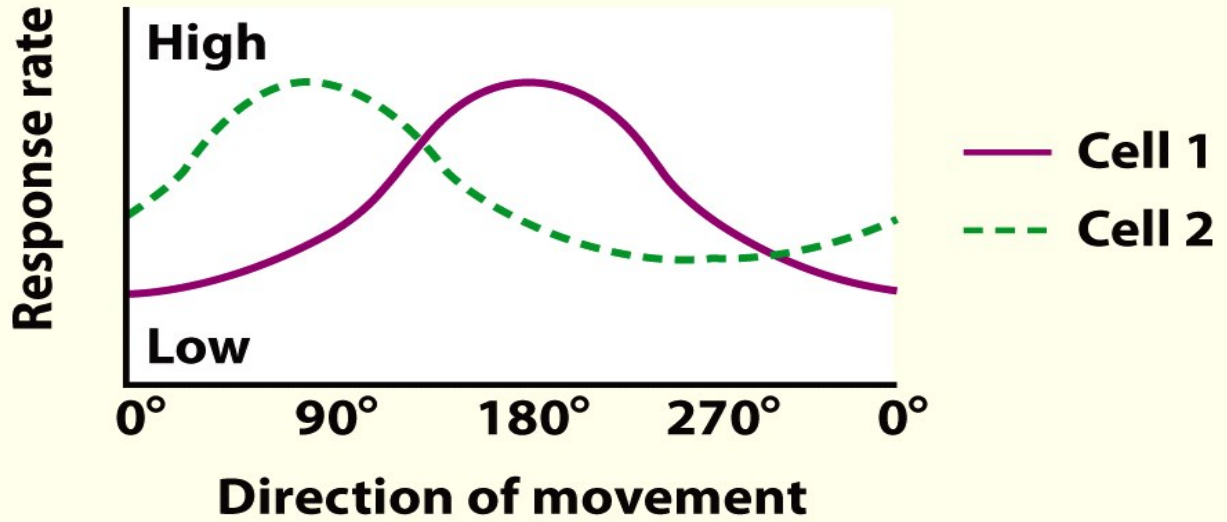
Neurons encode *direction* of movement

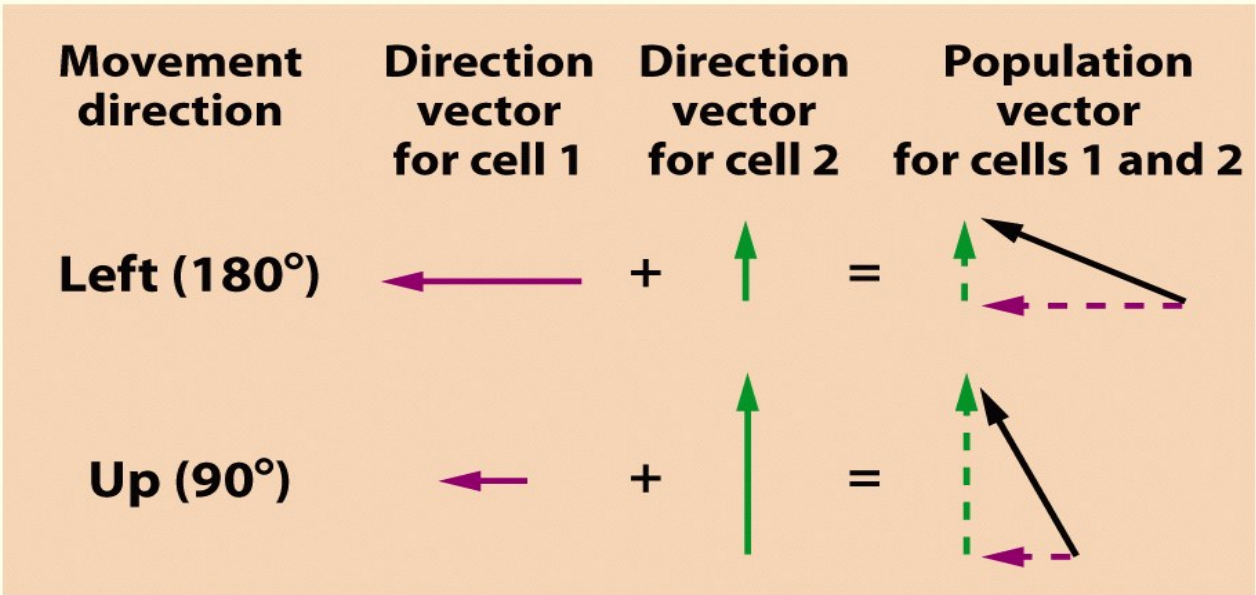
Direction Tuning of Primary Motor Cortex Neurons

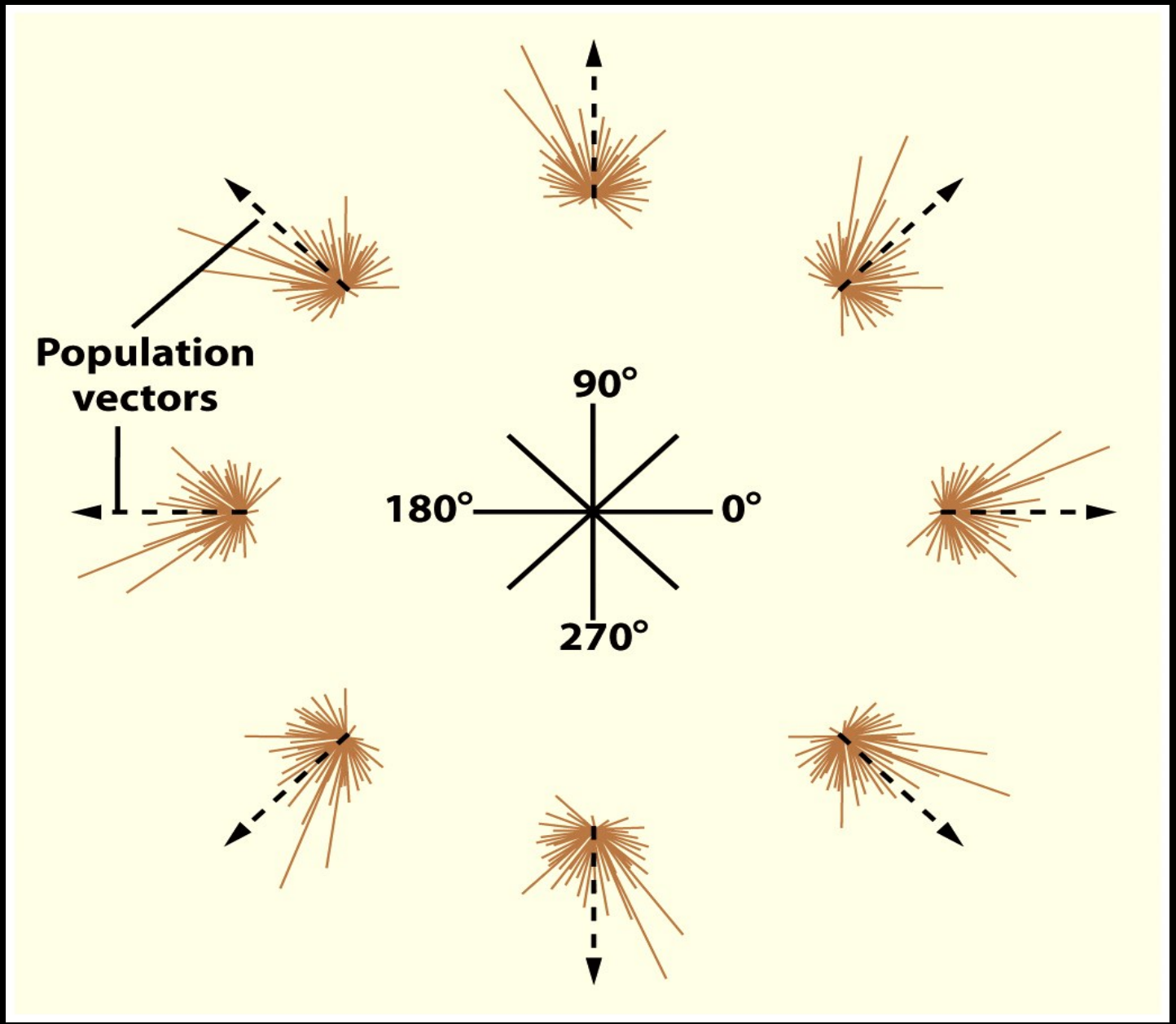


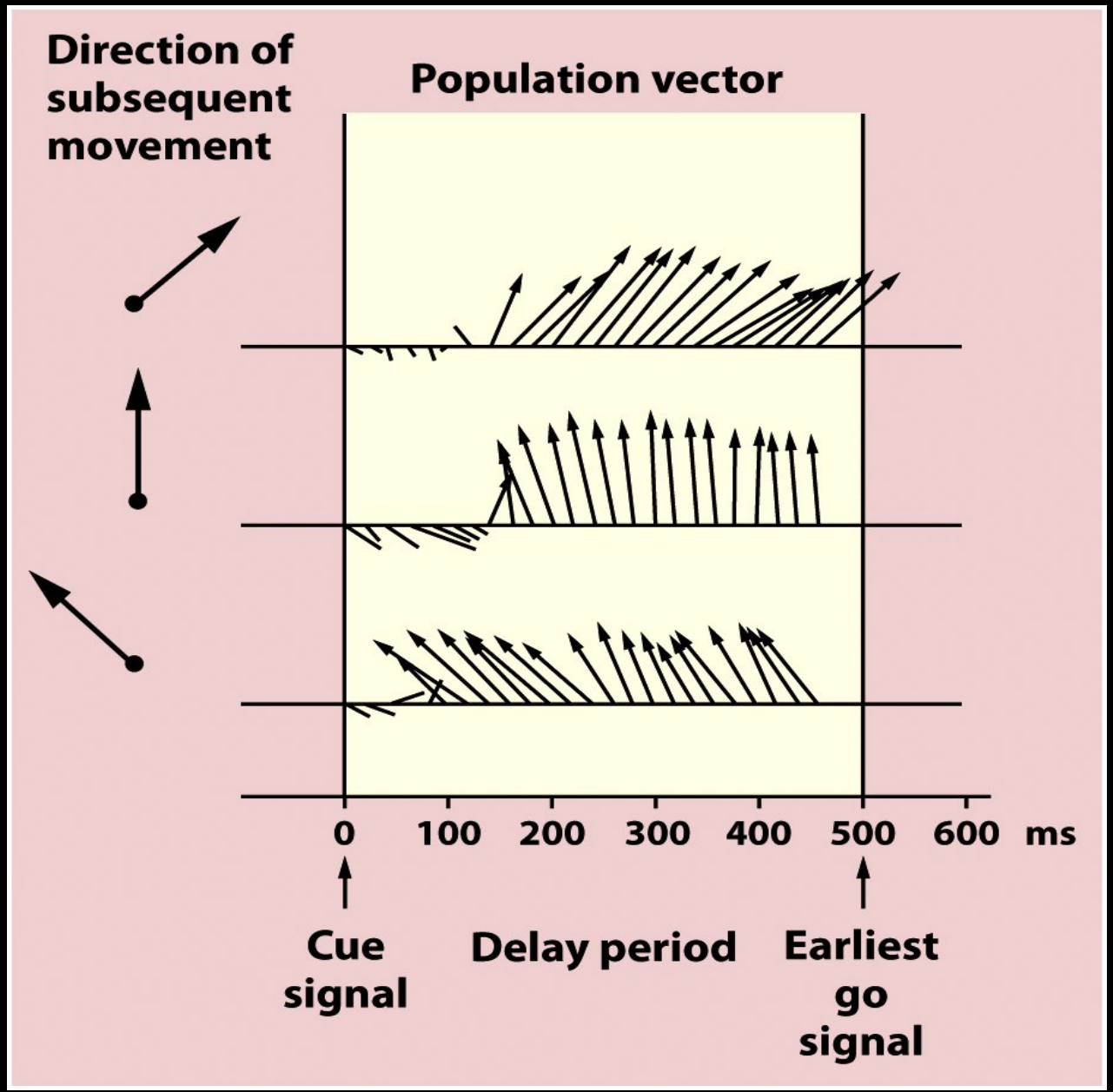
Georgopoulos AP et al. (1982) *J. Neurosci.* 2:1527-1537.


Tuning curve
Response rate
High
Low
0°
90°
180°
270°
0°
Direction of movement


Response rate
High
Low
0°
90°
180°
270°
0°
Direction of movement
Cell 1
Cell 2


Movement direction
Direction vector for cell 1
Direction vector for cell 2
Population vector for cells 1 and 2
Left (180°)
+
=
Up (90°)
+
=


Population vectors
90°
180°
0°
270°


Direction of subsequent movement
Population vector
0
100
200
300
400
500
600
ms
Cue signal
Delay period
Earliest go signal

Primary Motor Cortex (M1)

Neurons fire *before* the contraction of muscle

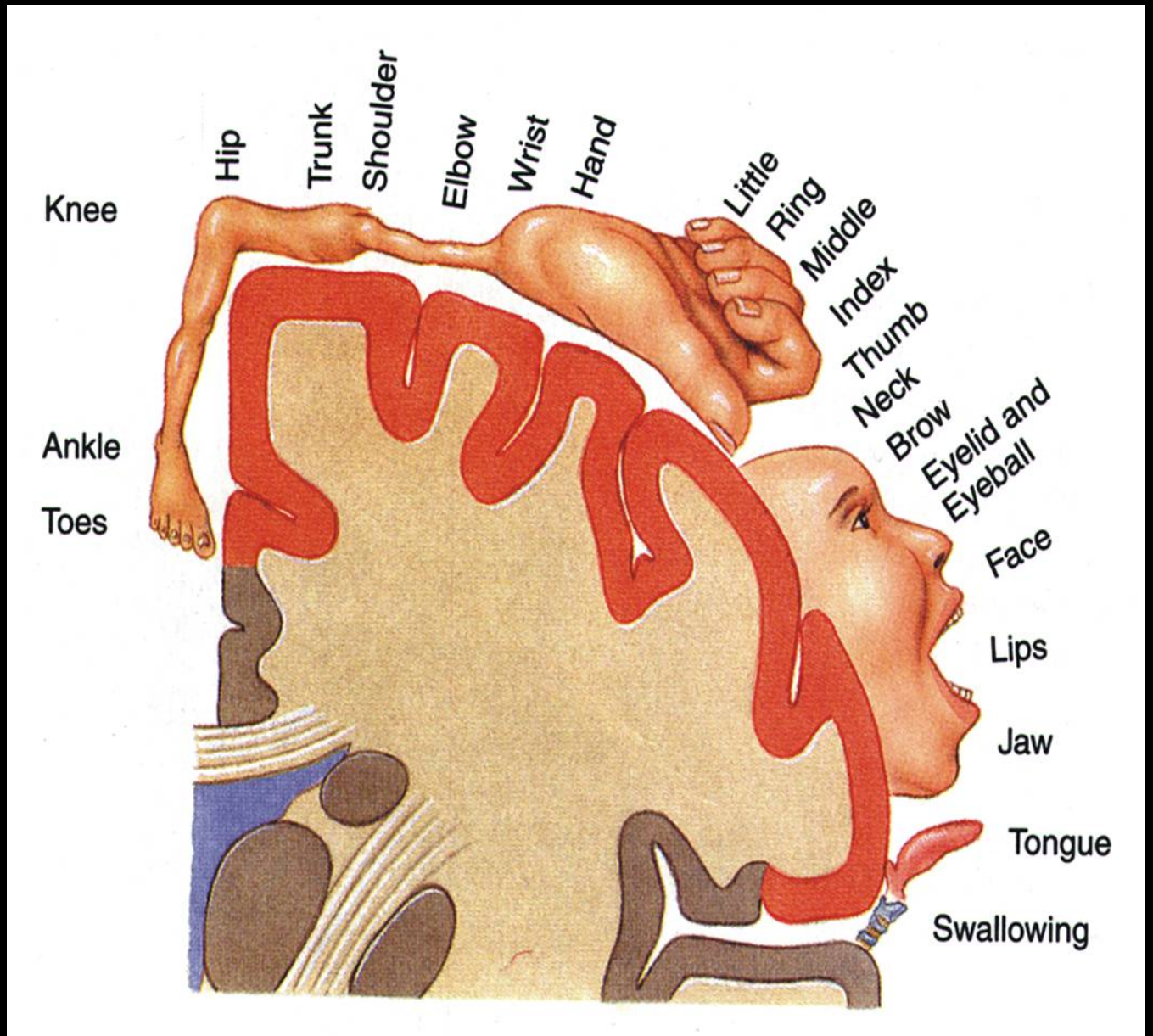
Neurons encode *force* of contraction

Neurons encode *direction* of movement

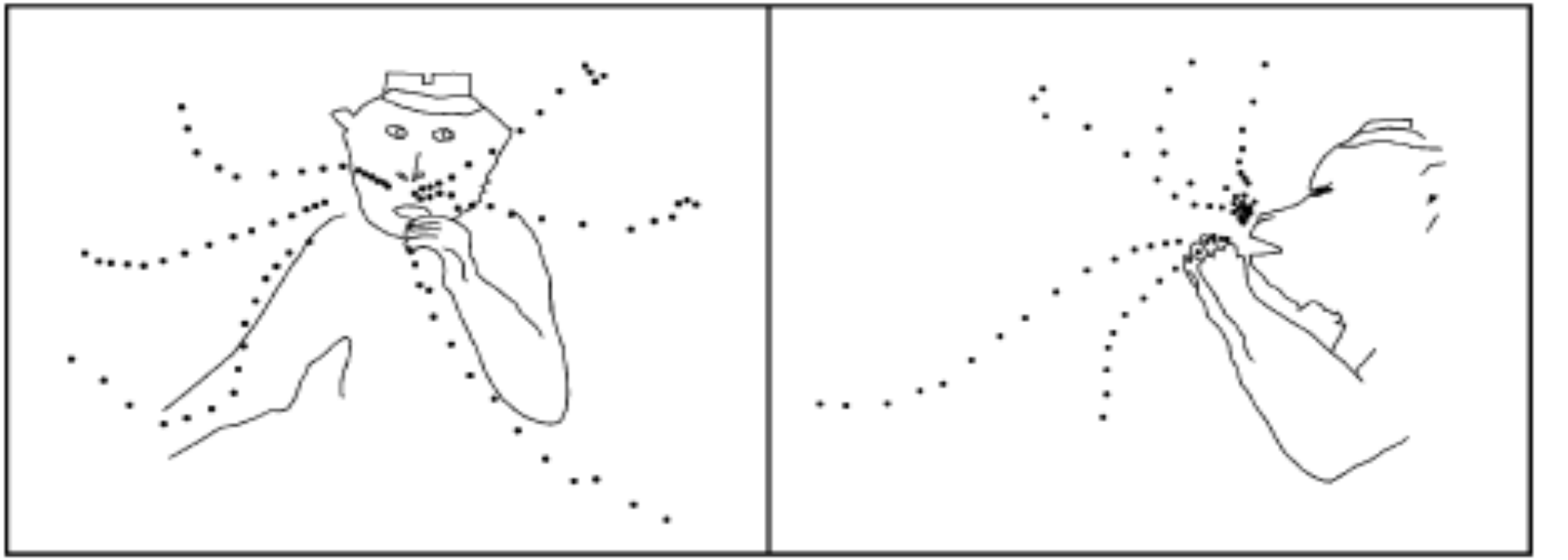
Neurons encode *extent* of movement

Neurons encode *speed* of movement

Motor Homunculus

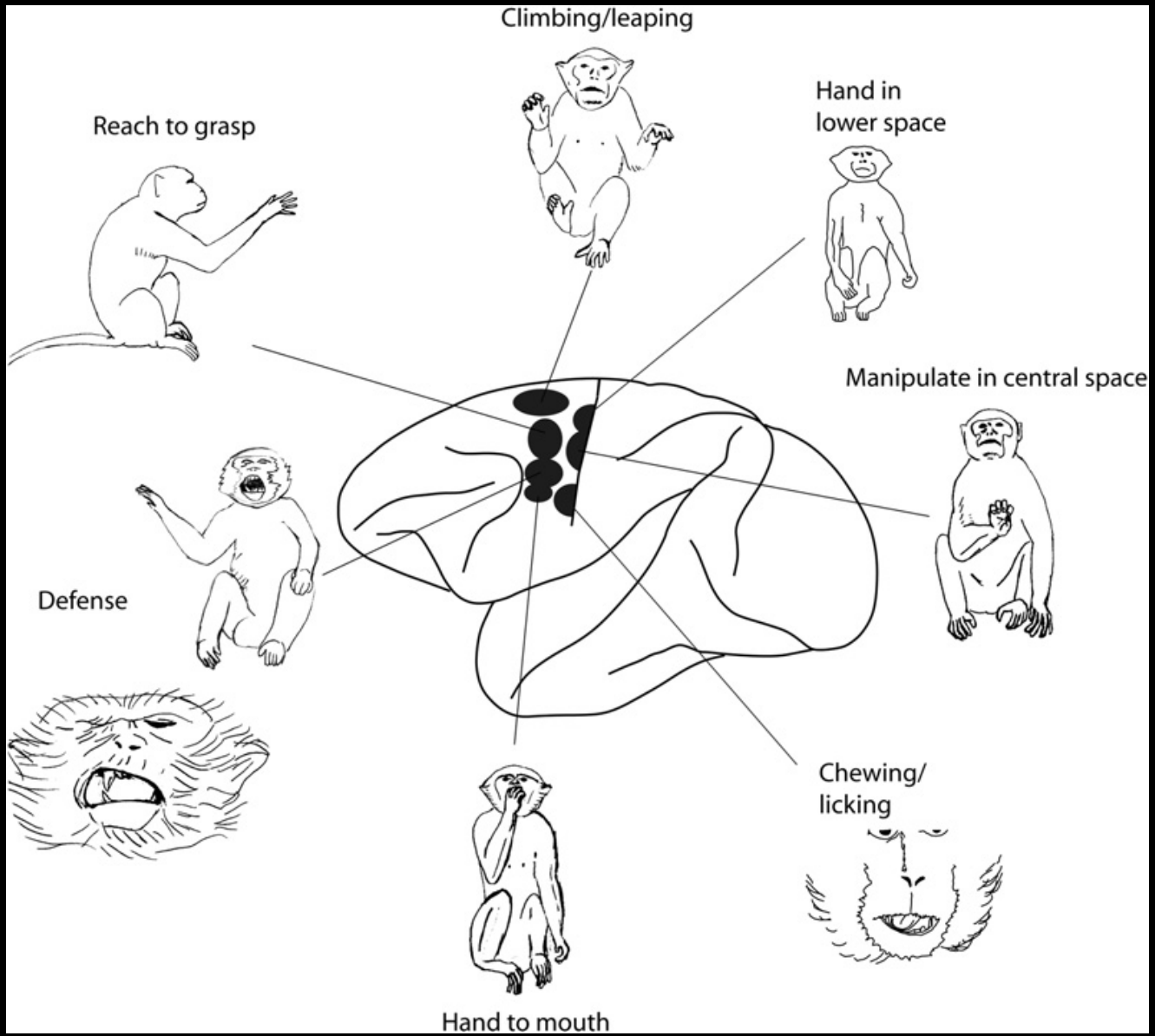


Long stimulation (e.g., 500 msec) of motor cortex elicits stereotyped postures



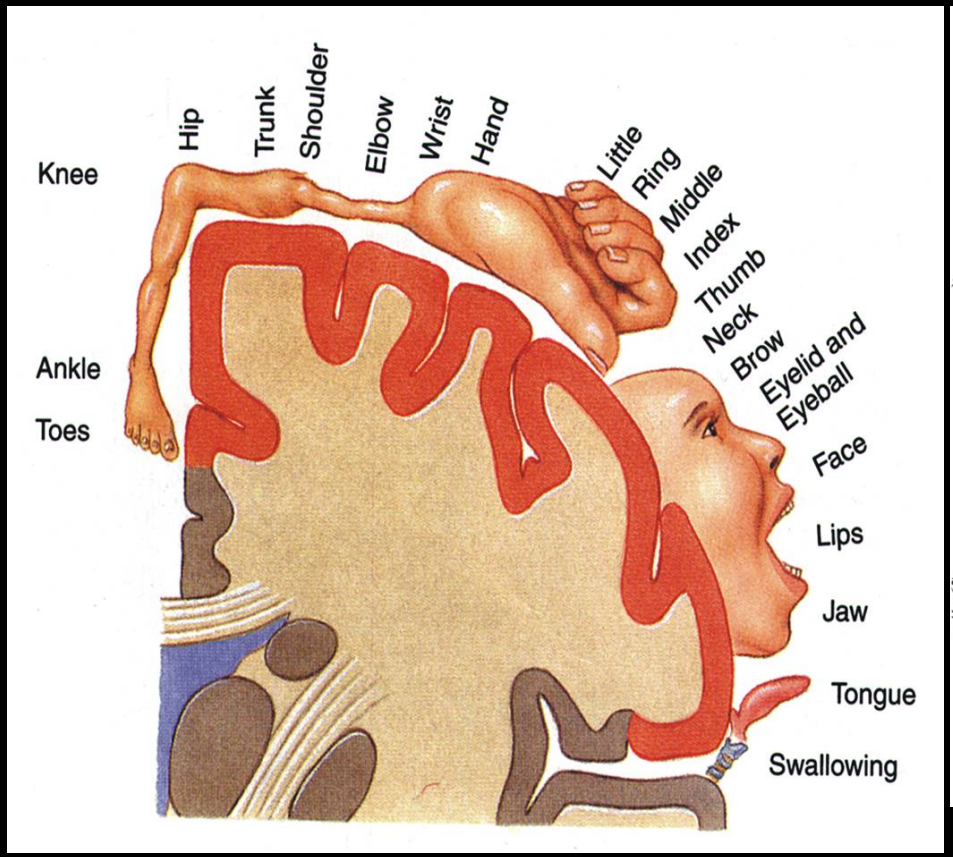
Graziano et al.,
Neuron, 2002 34:841-51.

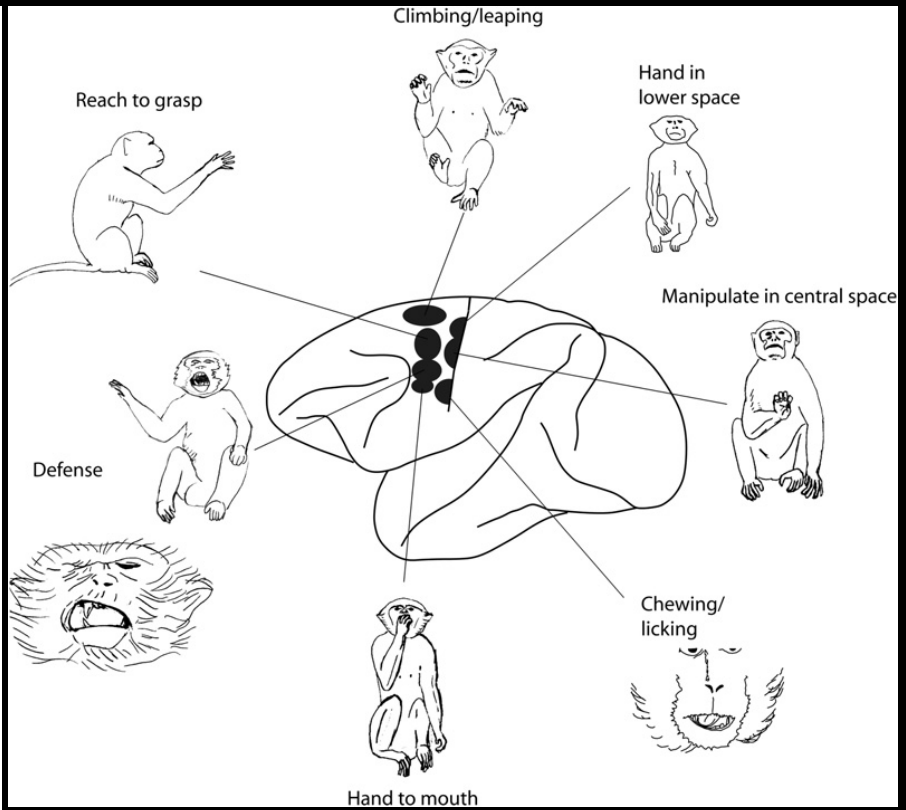
Action Zones



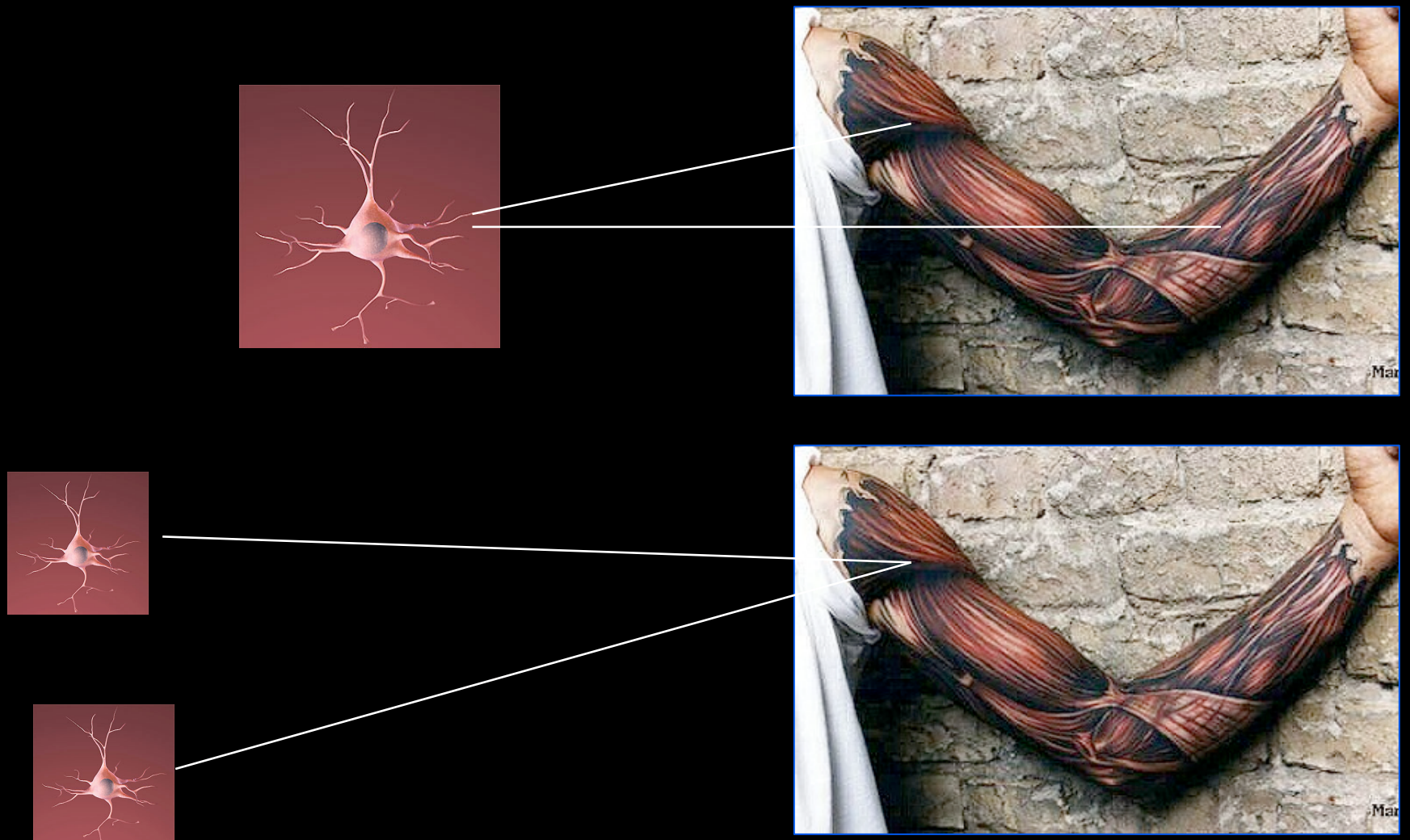
Aflalo & Graziano,
Neuron, 2007

Motor Homunculus vs. Action Zones



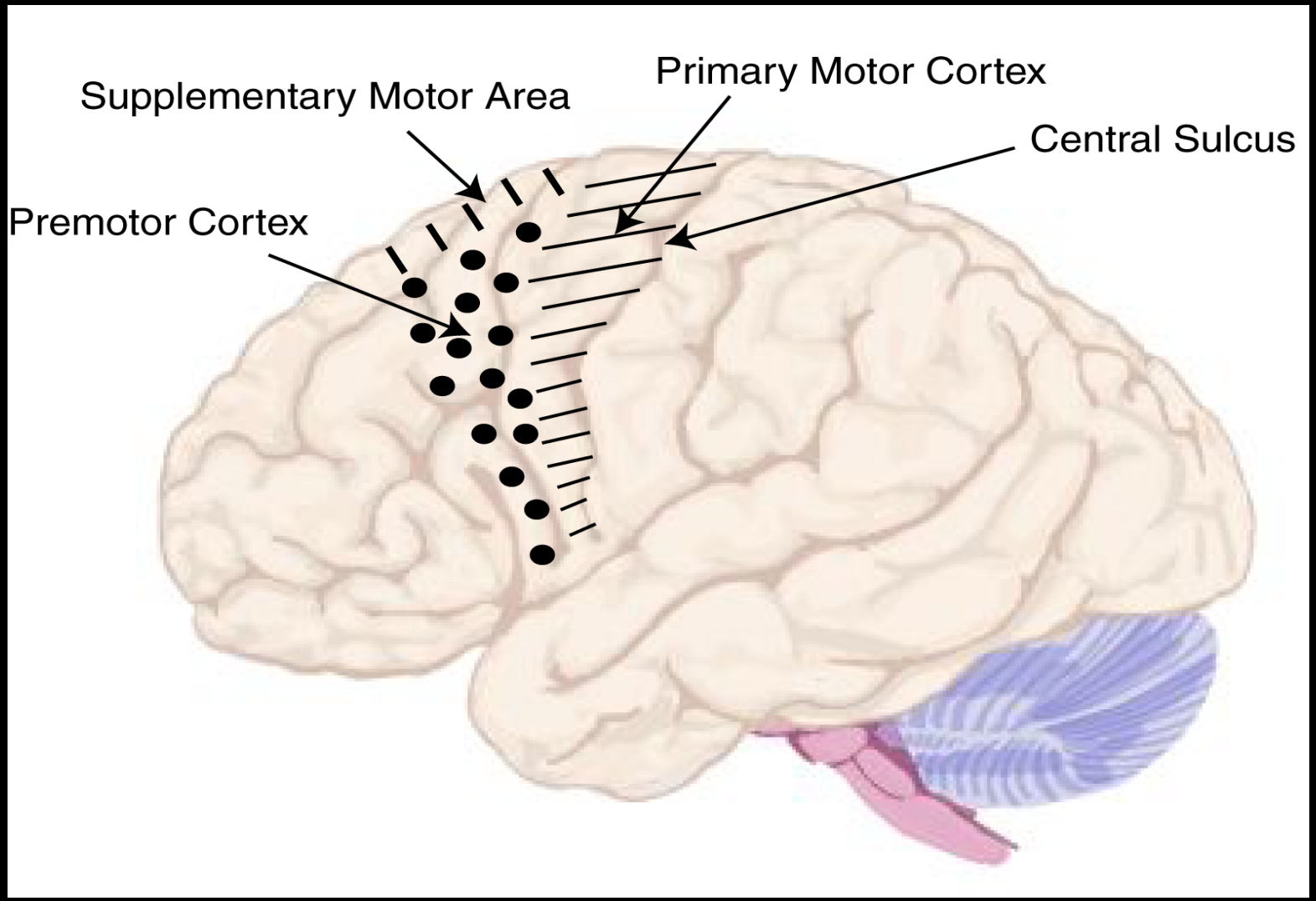


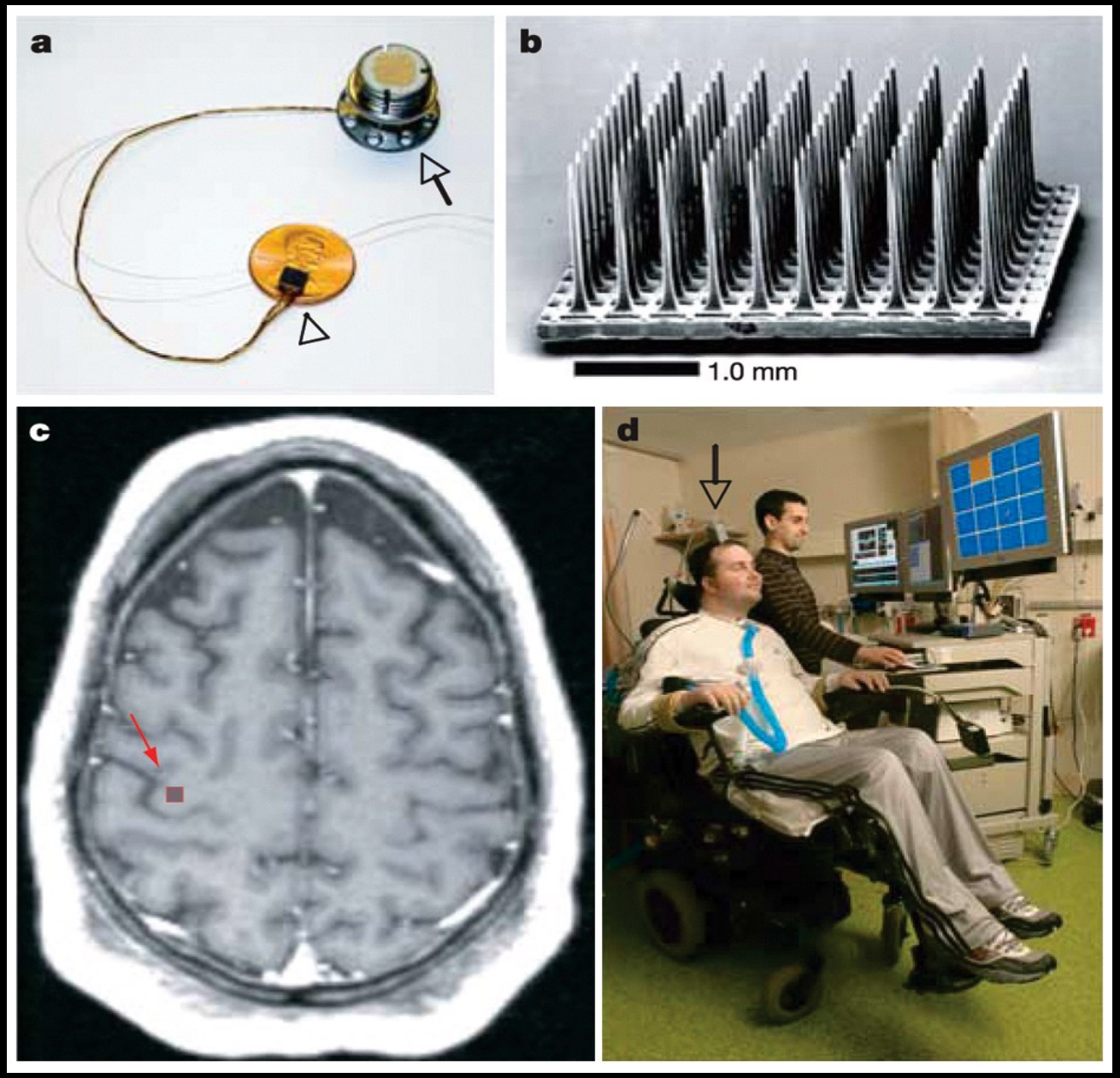
Divergence and Convergence

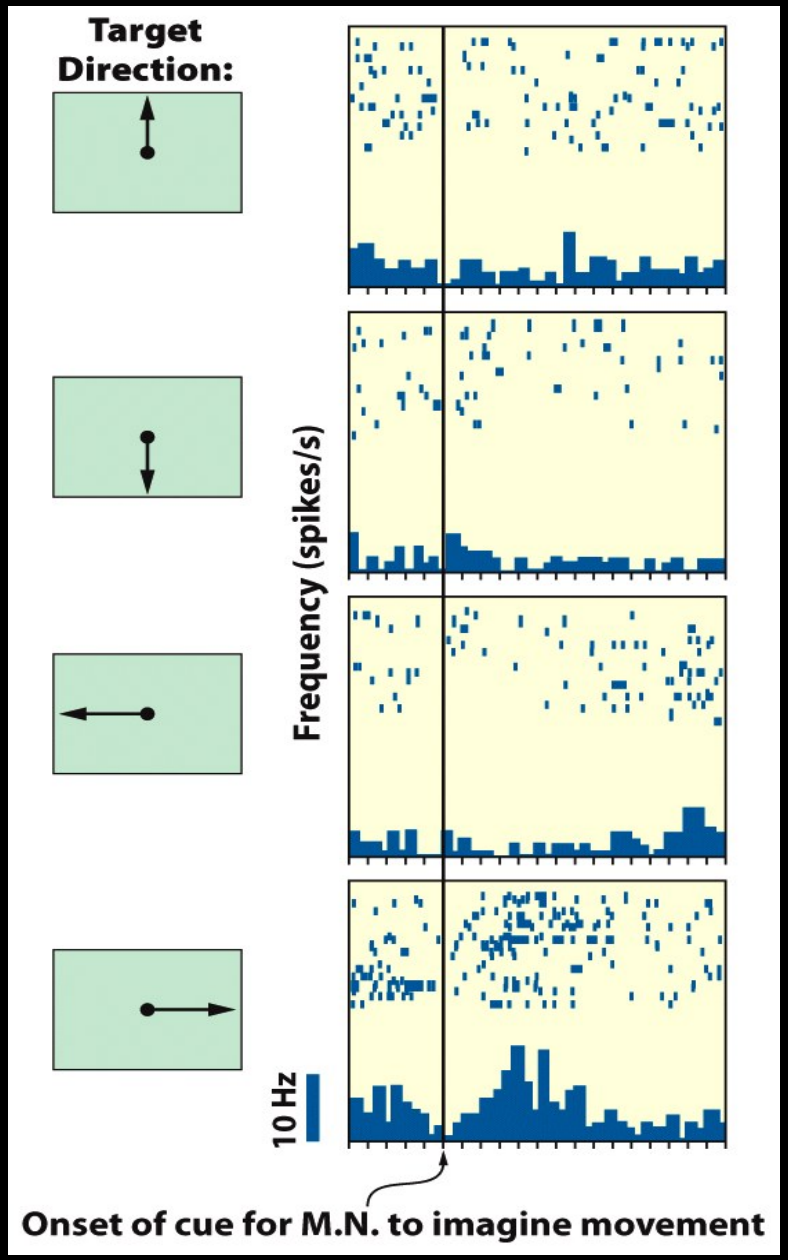



MODBLOG
BMEZINE.COM

Motor Cortex



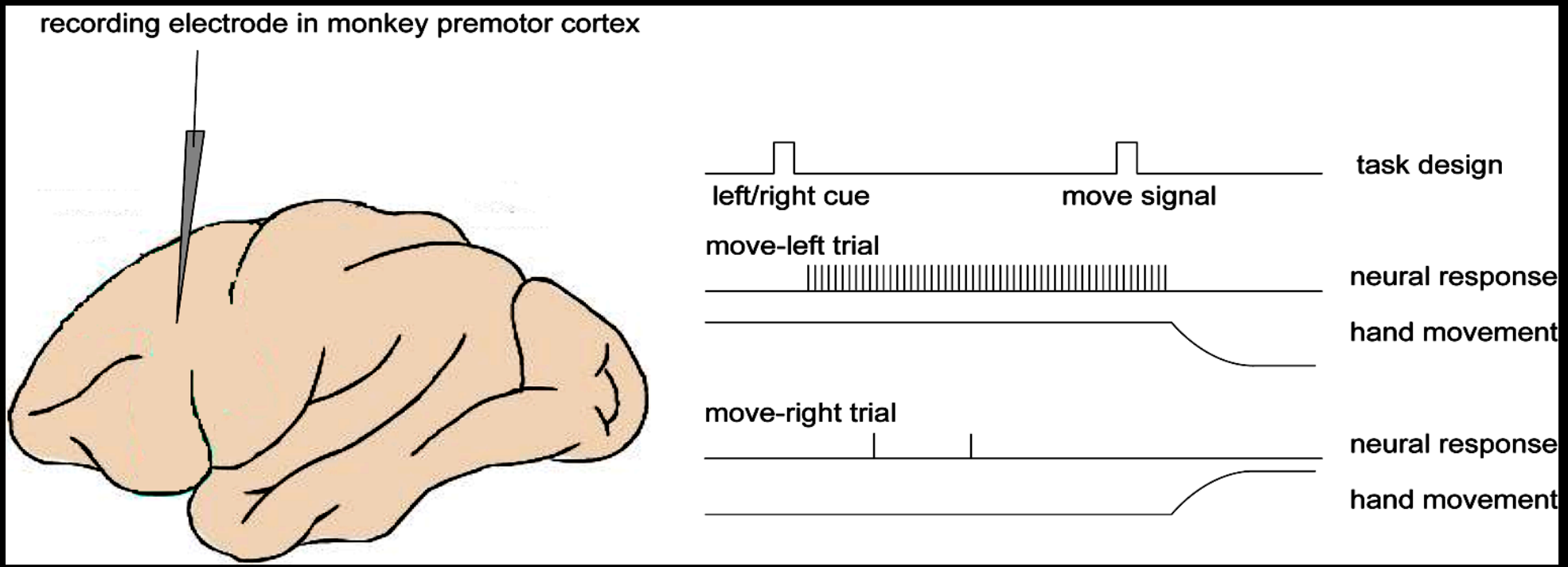

a
b
1.0 mm
c
d


Target Direction:
Frequency (spikes/s)
10 Hz
Onset of cue for M.N. to imagine movement

Premotor Cortex

Preparation for movement (“Motor set”)

Premotor cortex is involved in preparation for movement

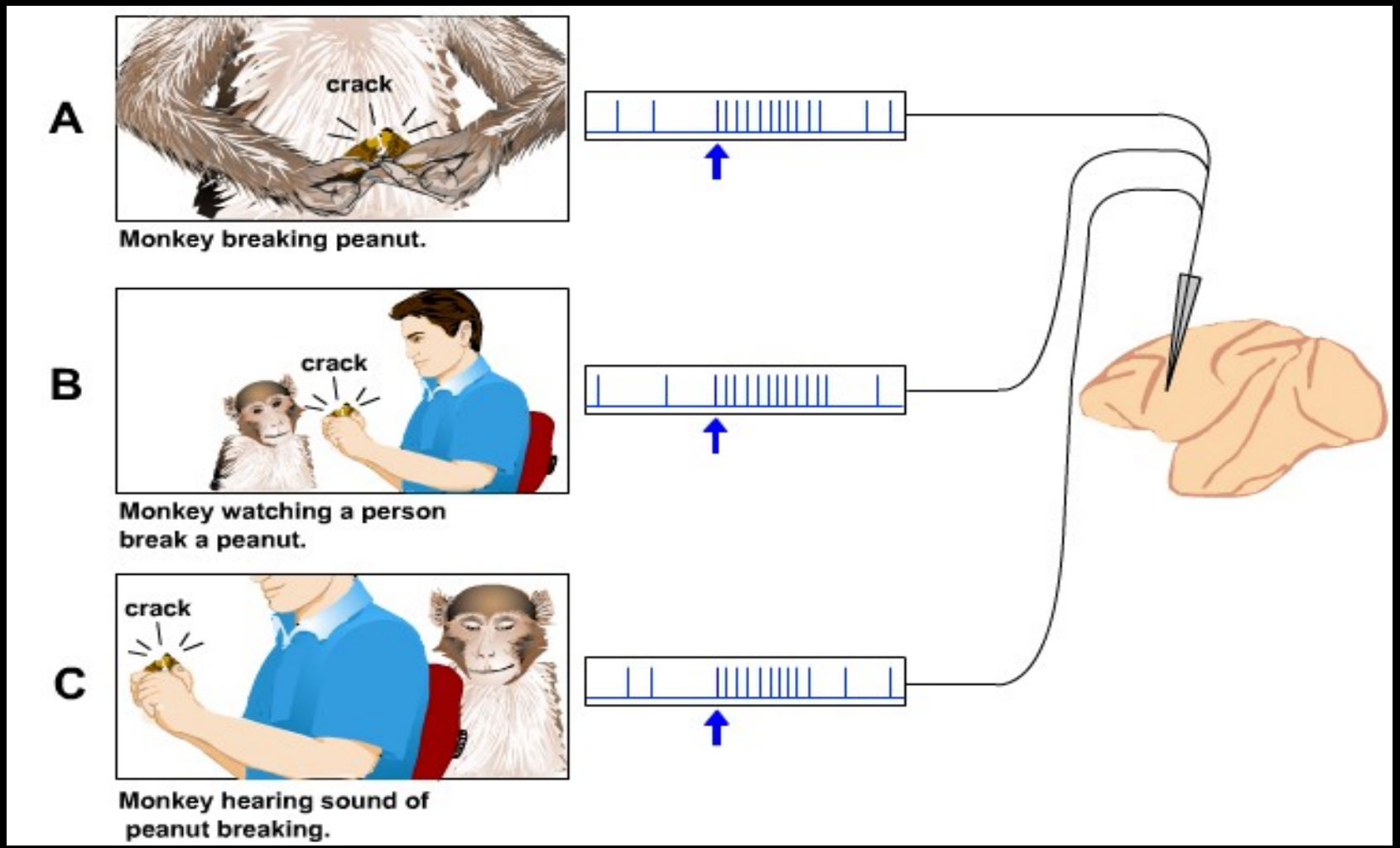


Premotor Cortex

Preparation for movement ("Motor set")

Sensory aspects associated with motor acts

Premotor Cortex “Mirror” Neuron



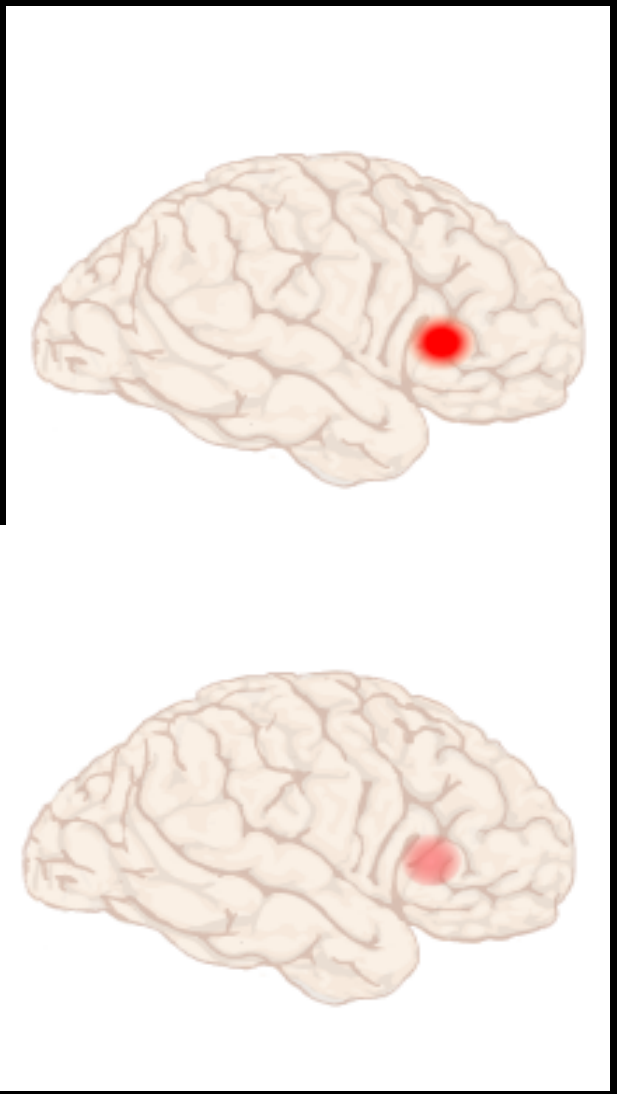
Premotor Cortex

Preparation for movement ("Motor set")

Sensory aspects associated with motor acts

Behavioral context

Premotor cortex encodes behavioral context



Premotor Cortex

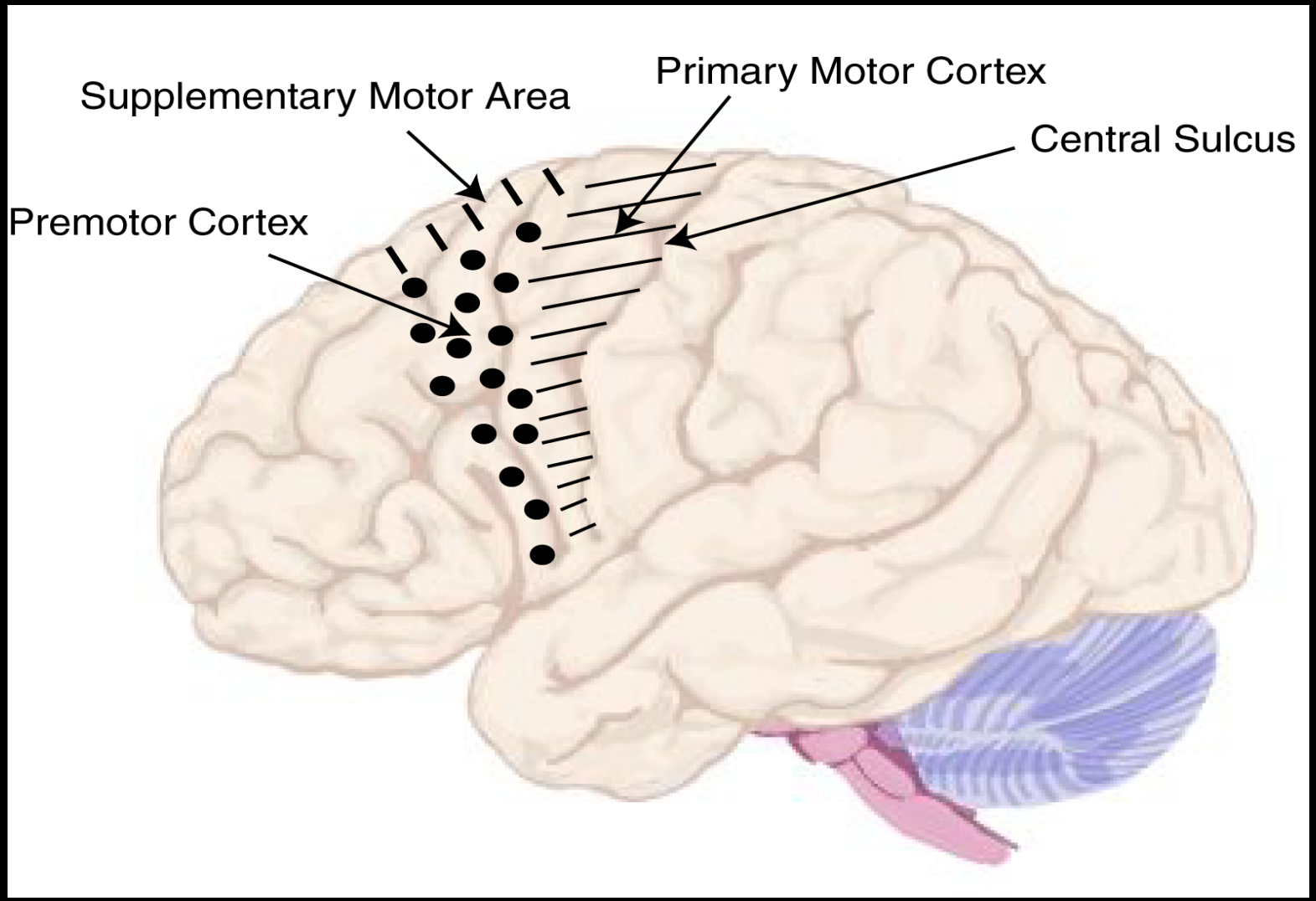
Preparation for movement ("Motor set")

Sensory aspects associated with motor acts

Behavioral context

Signals correct and incorrect actions

Motor Cortex

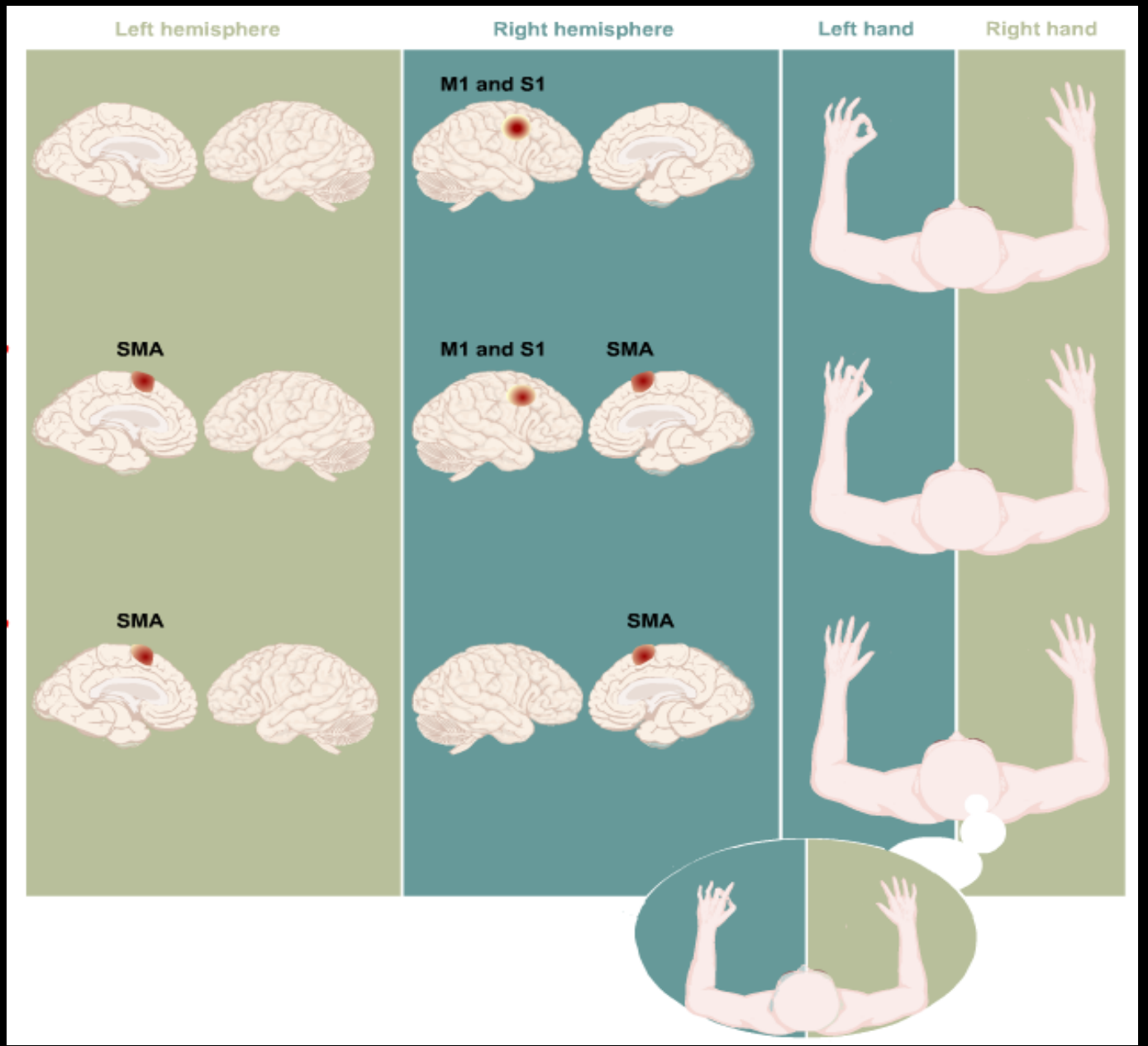


Supplementary Motor Area

Programming complex sequences of movements

Coordination of bilateral movements

Transformation of kinematic to dynamic information

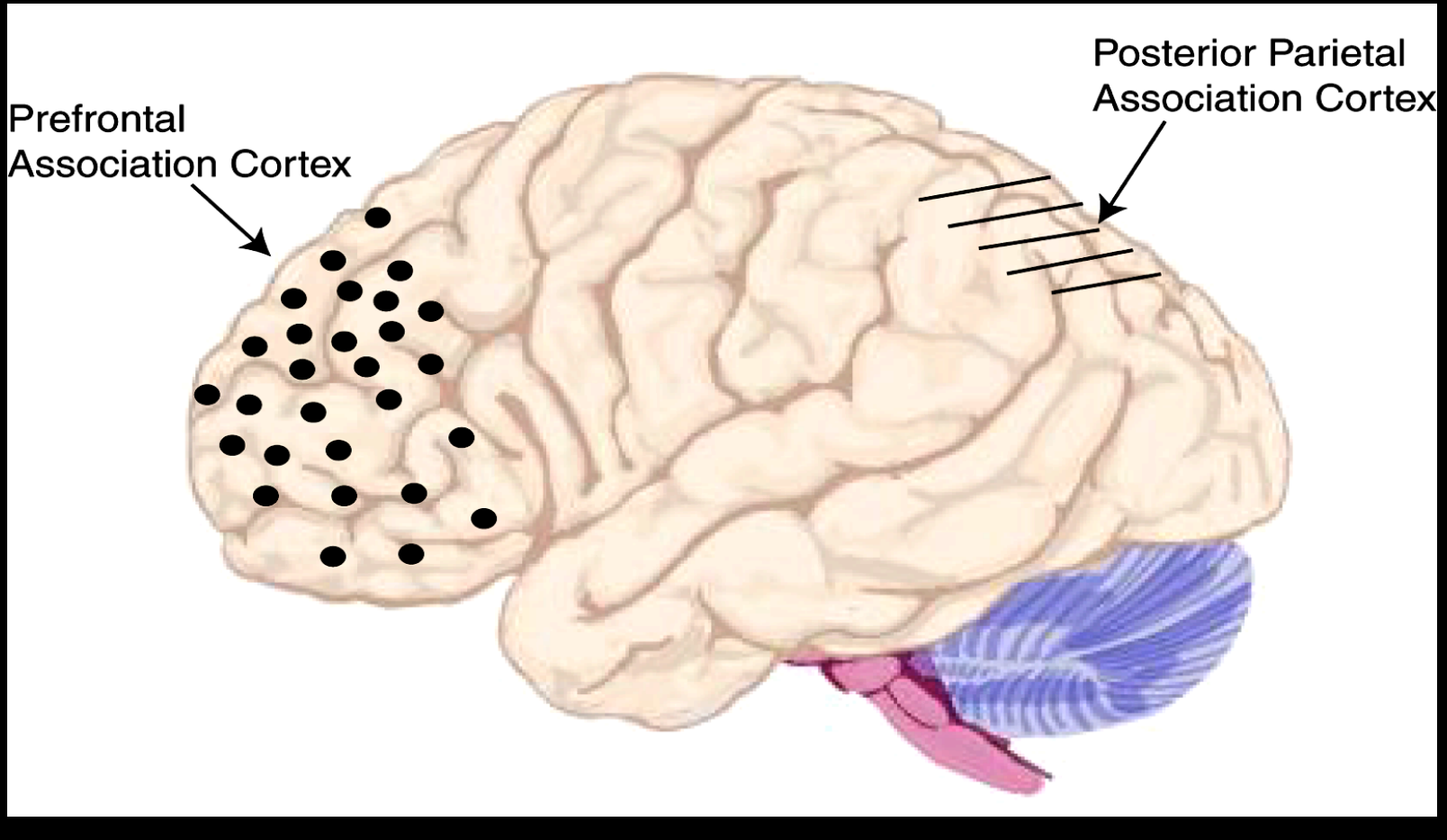

Left hemisphere
Right hemisphere
Left hand
Right hand
M1 and S1
SMA
M1 and S1
SMA
SMA
SMA

Supplementary Motor Area

Programming complex sequences of movements

Coordination of bilateral movements

Transformation of kinematic to dynamic information


Prefrontal
Association Cortex
Posterior Parietal
Association Cortex

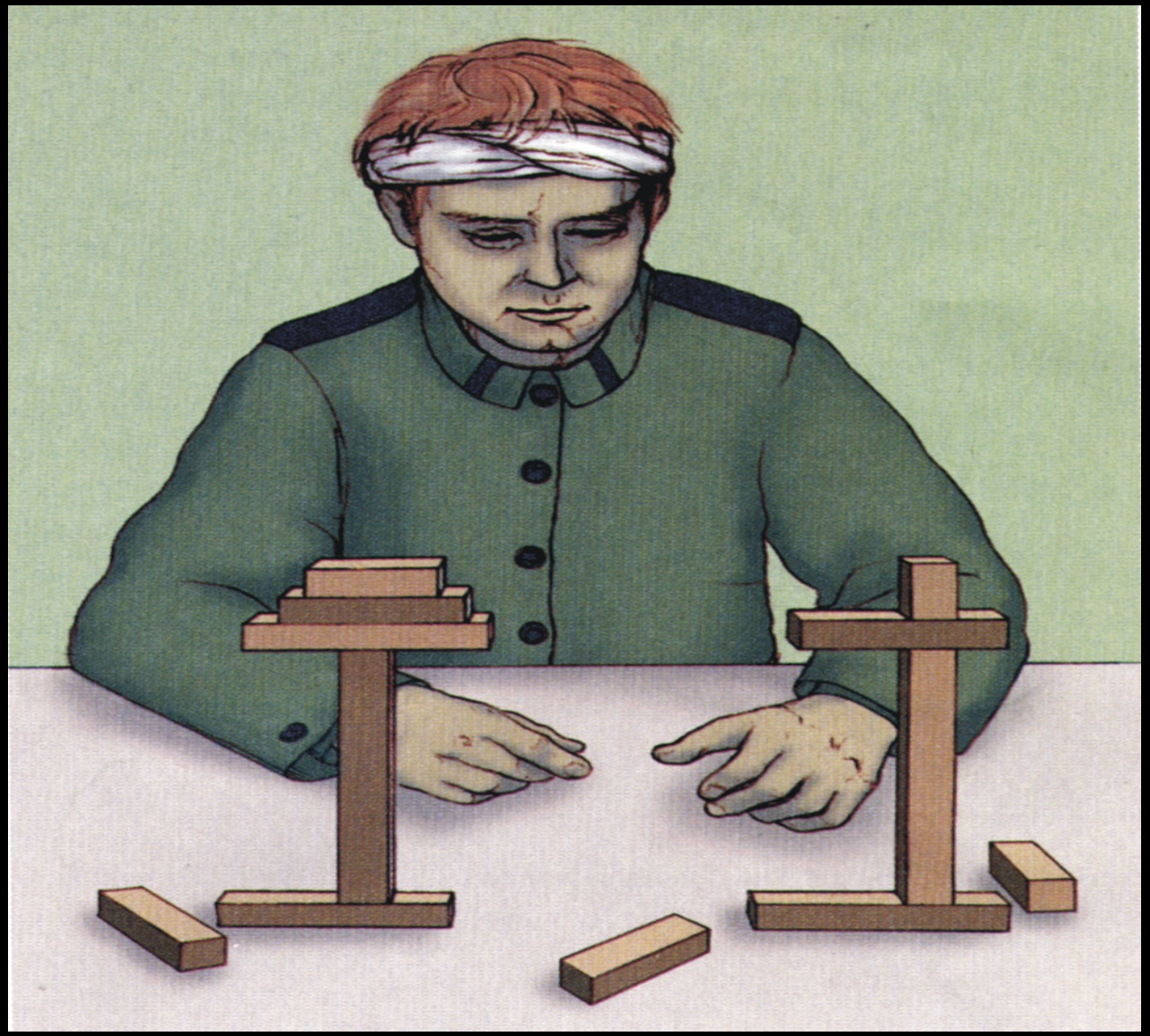
Association Cortex

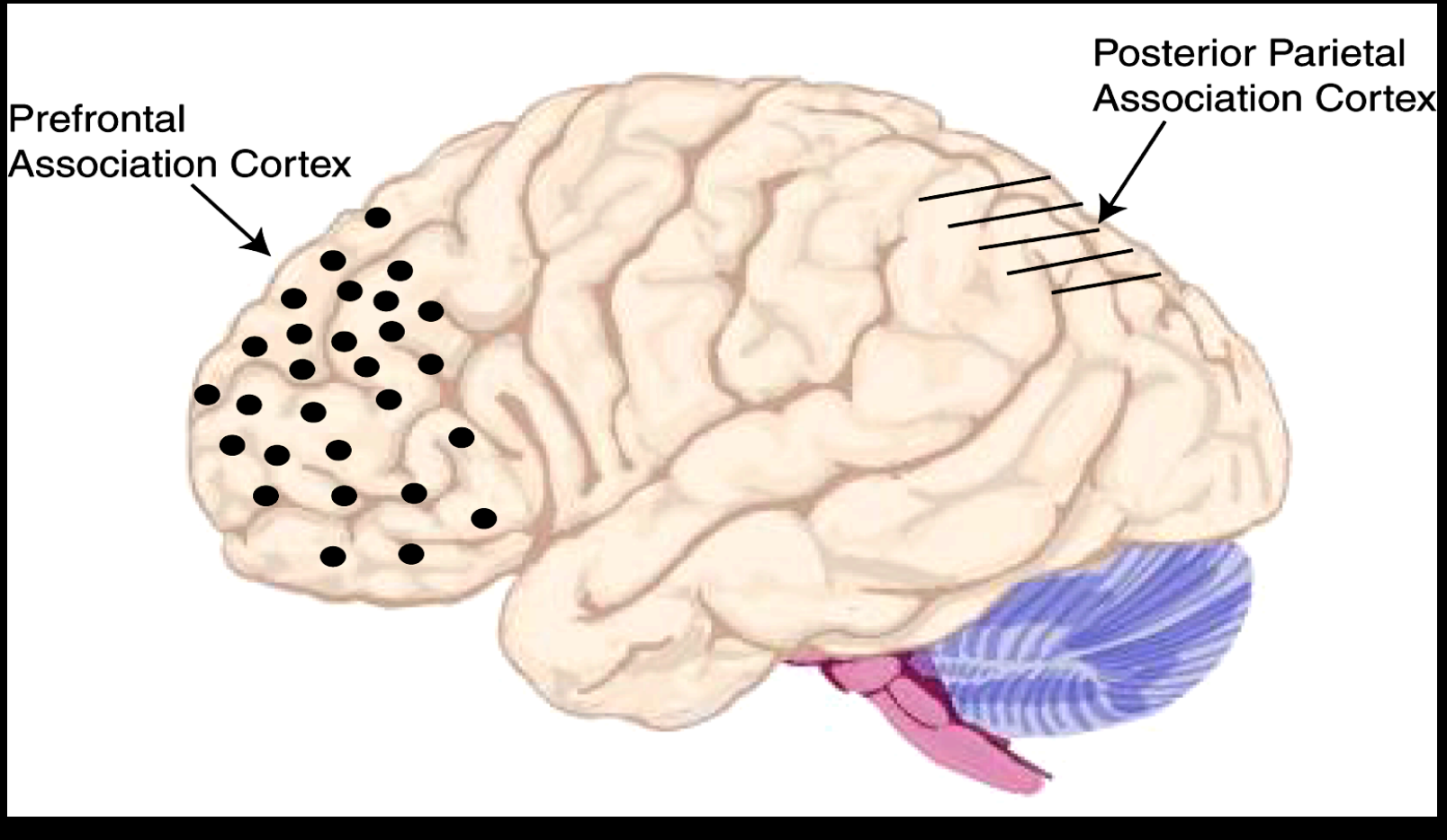
4th hierarchical level

Goals, context, attention, spatial layout of environment

Posterior parietal cortex

Constructional Apraxia




Prefrontal
Association Cortex
Posterior Parietal
Association Cortex

Hierarchical Organization and Functional Segregation of Central Motor Structures