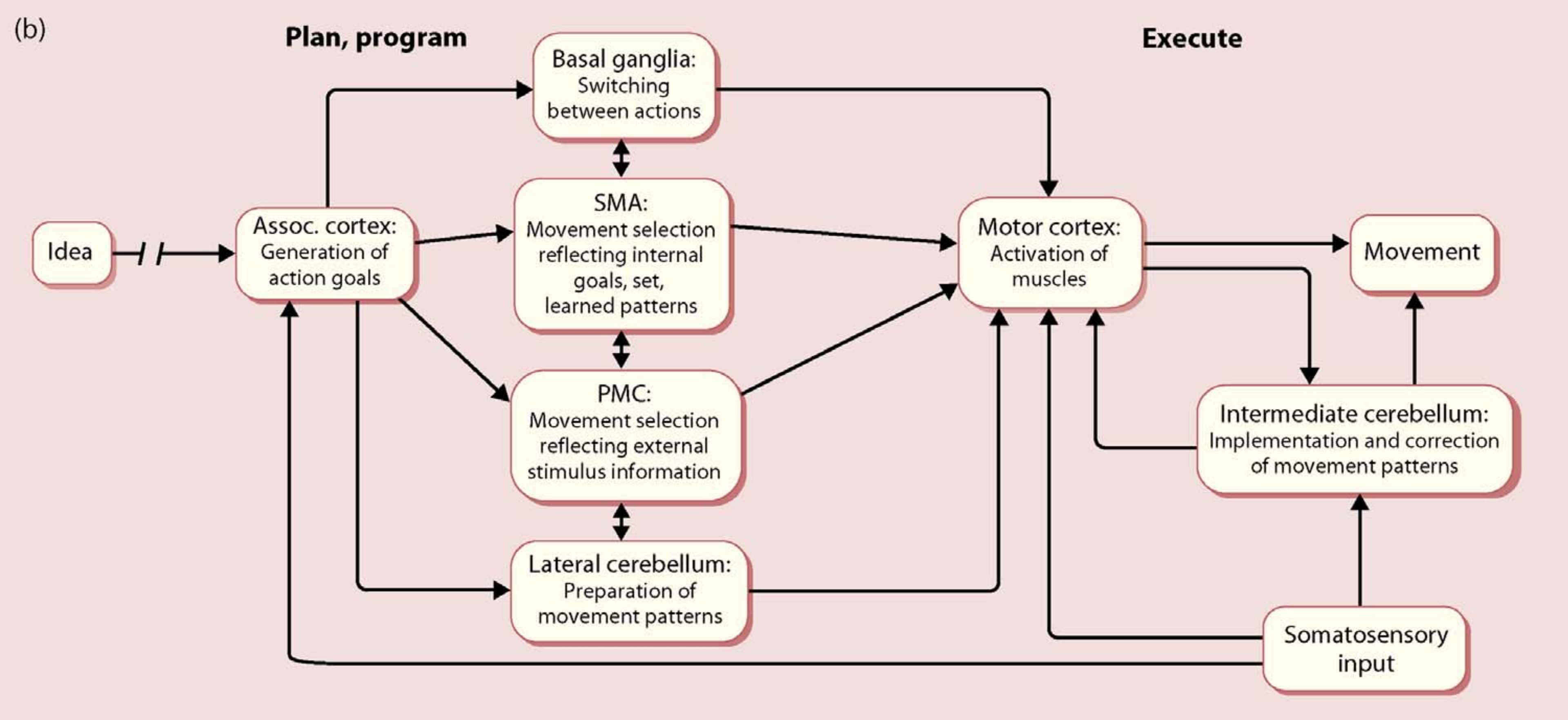


(b)

Plan, program

Execute

Idea

Assoc. cortex: Generation of action goals

Basal ganglia: Switching between actions

SMA: Movement selection reflecting internal goals, set, learned patterns

PMC: Movement selection reflecting external stimulus information

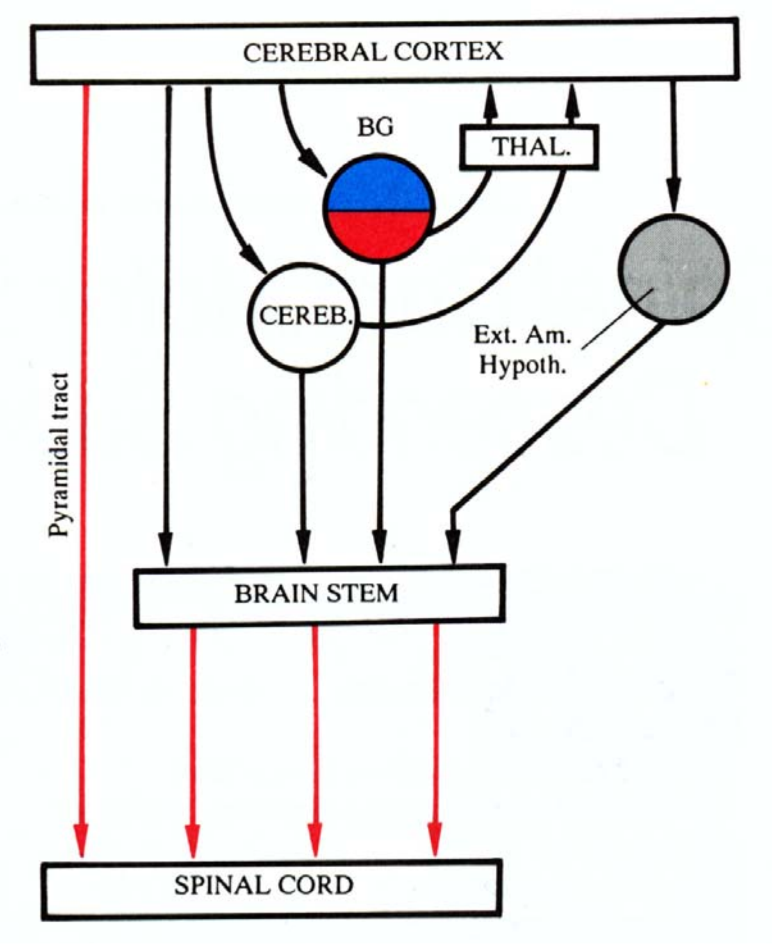
Lateral cerebellum: Preparation of movement patterns

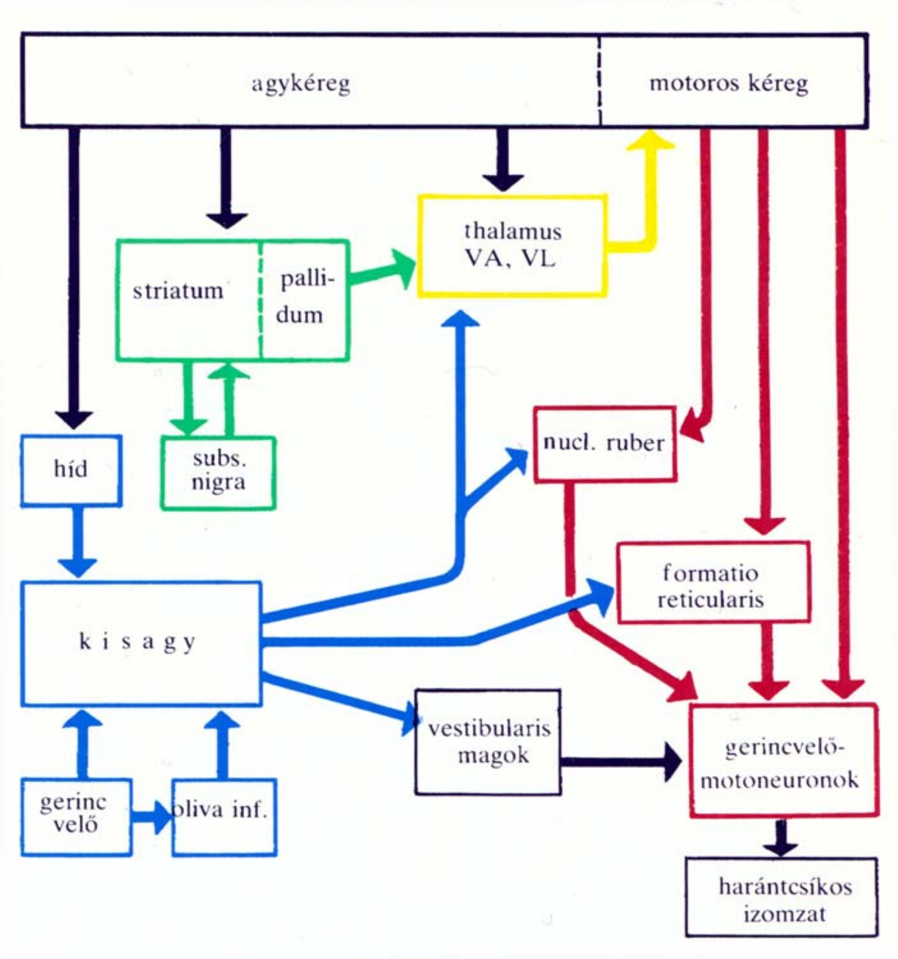
Motor cortex: Activation of muscles

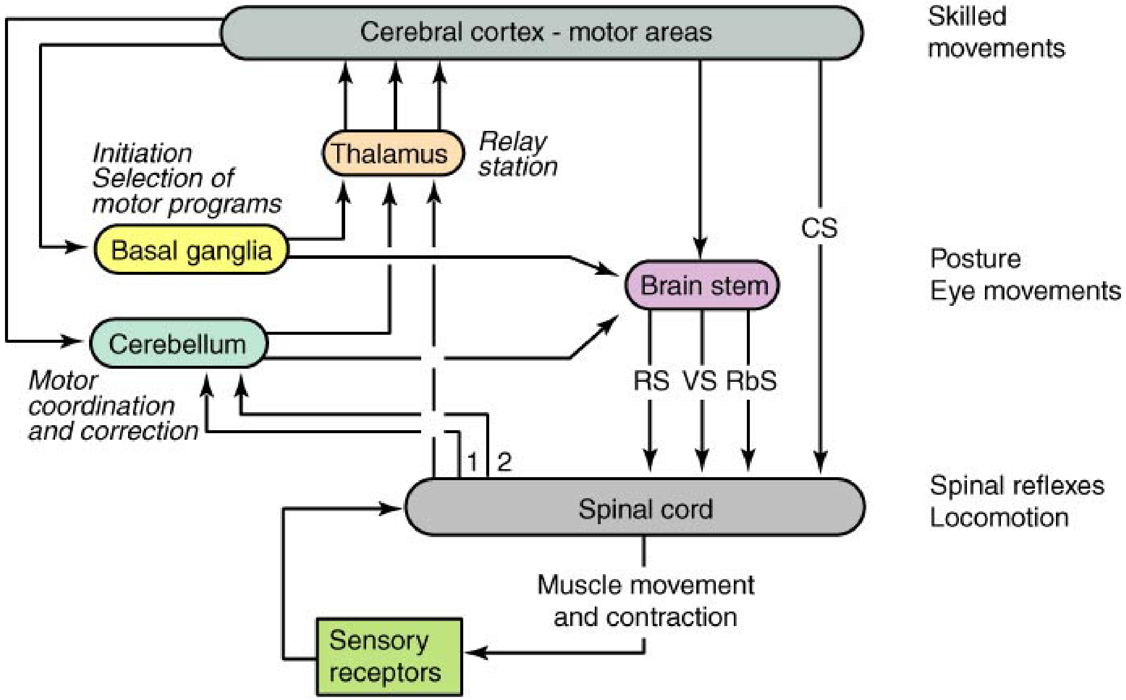
Movement

Intermediate cerebellum: Implementation and correction of movement patterns

Somatosensory input


CEREBRAL CORTEX
BG
THAL.
CEREB.
Ext. Am.
Hypoth.
Pyramidal tract
BRAIN STEM
SPINAL CORD


agykéreg
motoros kéreg
thalamus
VA, VL
striatum
palli-
dum
subs.
nigra
híd
nucl. ruber
formatio
reticularis
kisagy
vestibularis
magok
gerincvelő-
motoneuronok
gerinc
velő
oliva inf.
harántcsíkos
izomzat

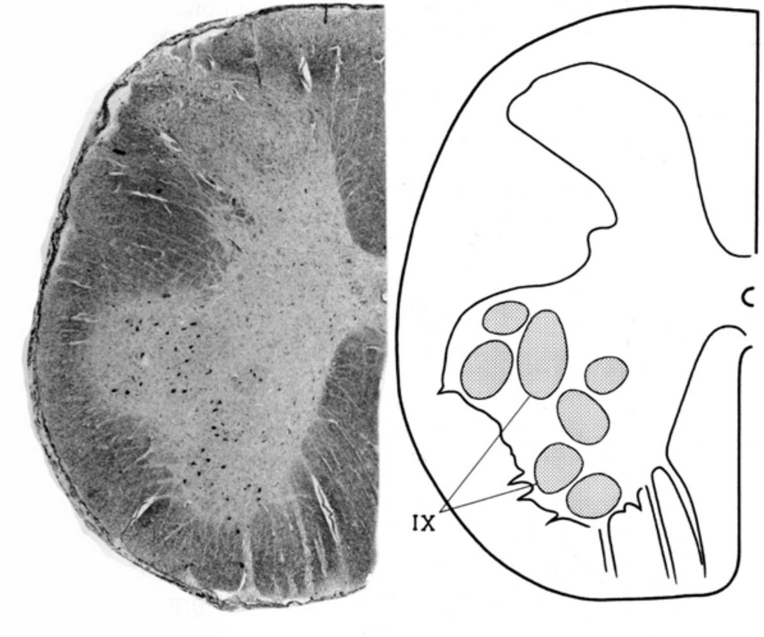


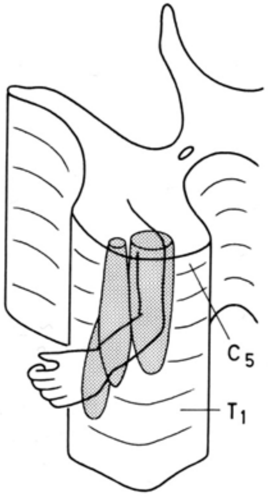
Basic functions of descending tracts

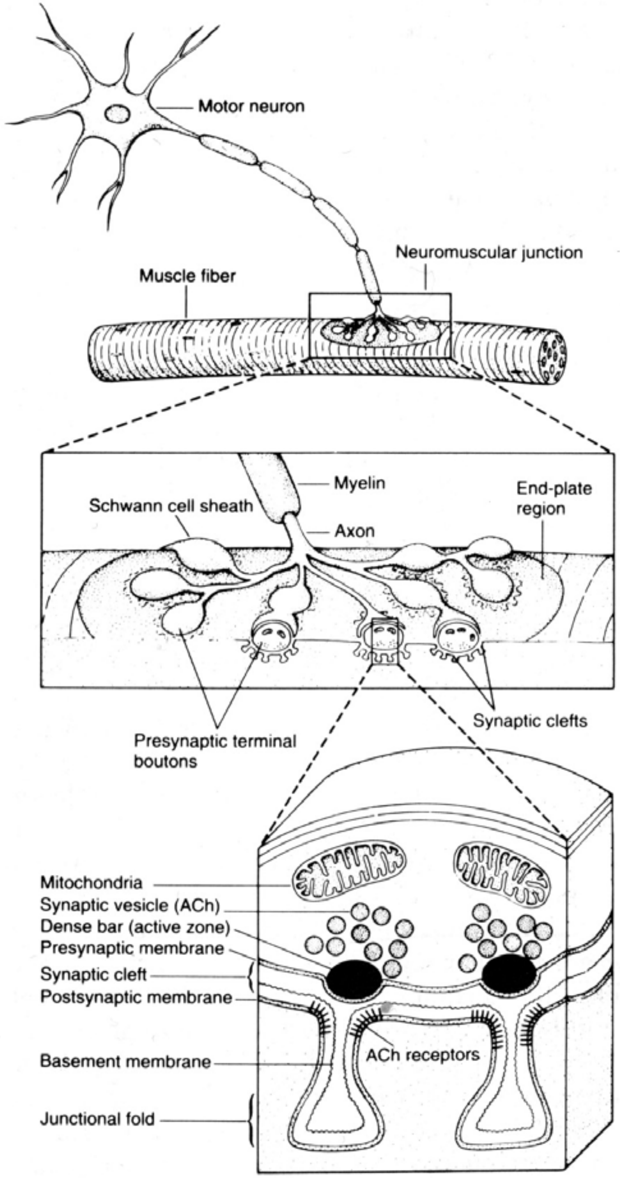
Cortico- and rubrospinal
1. Transmission of commands for skilled movements.
2. Corrections of motor patterns generated by the spinal cord.

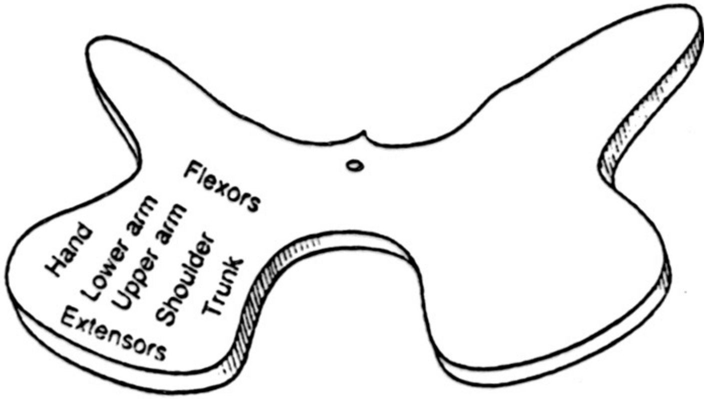
Reticulospinal
1. Activation of spinal motor programs for stepping and other stereotypic movements.
2. Control of upright body posture.

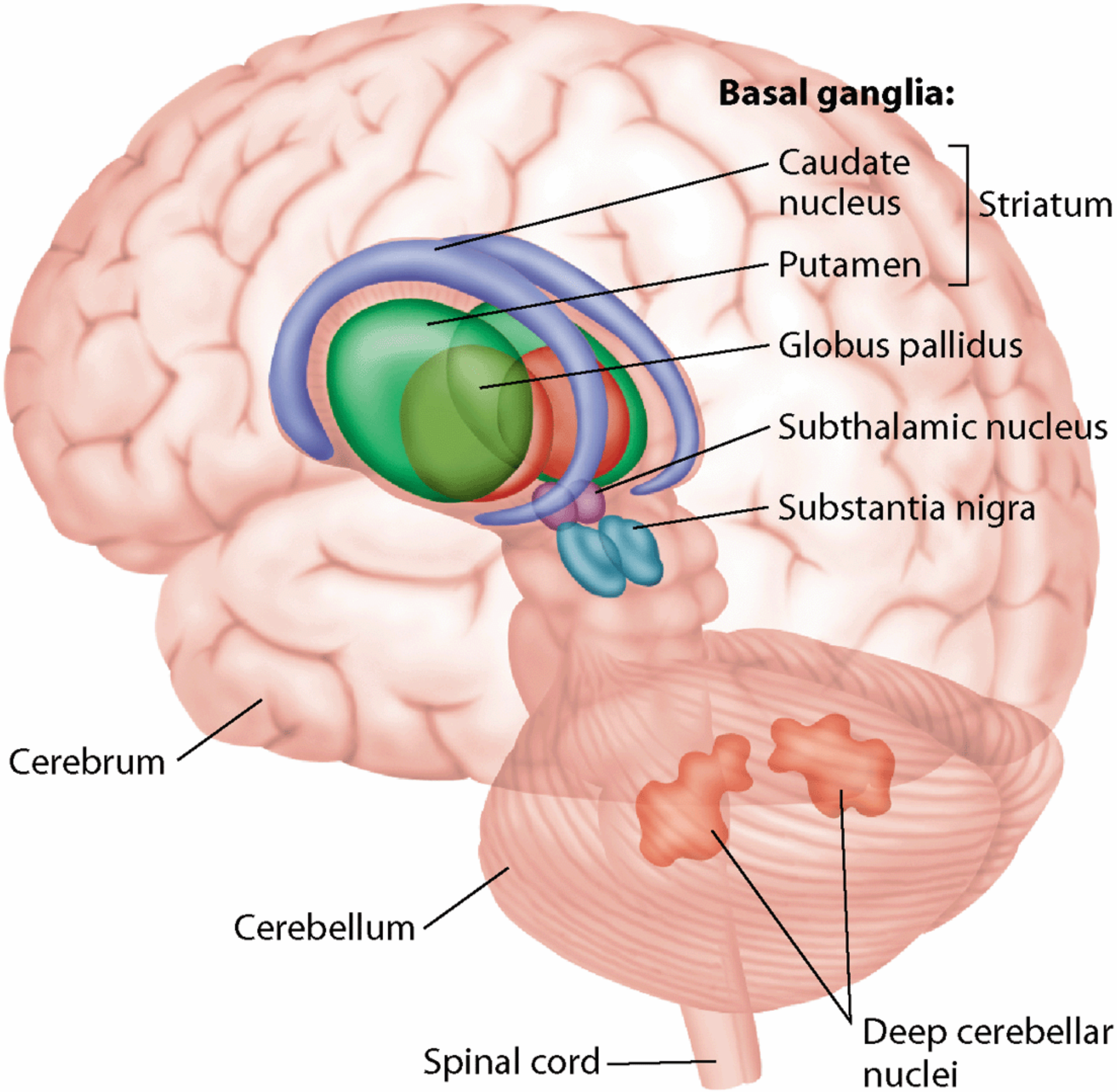
Vestibulospinal
Generation of tonic activity in antigravity muscles

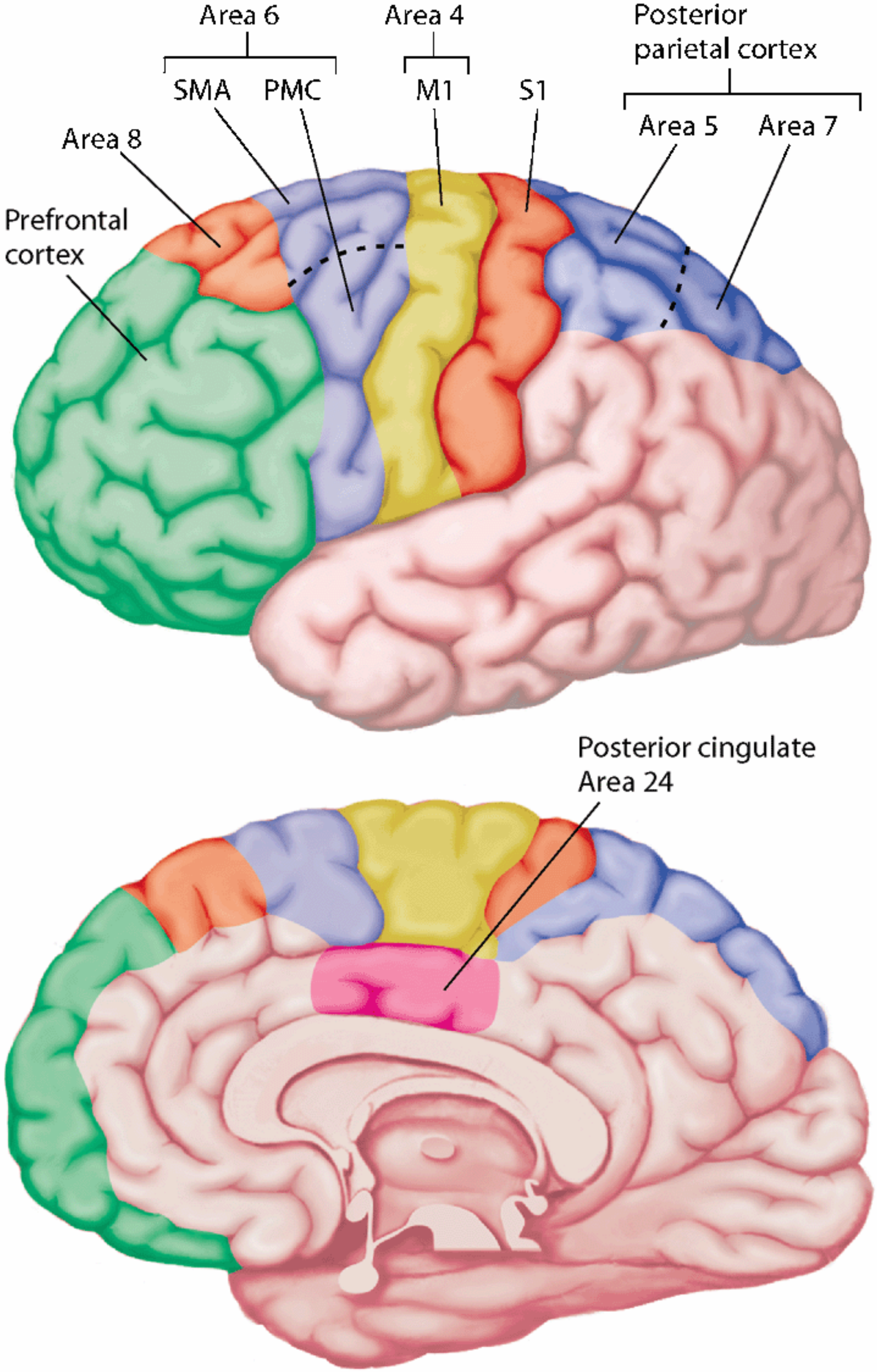

IX

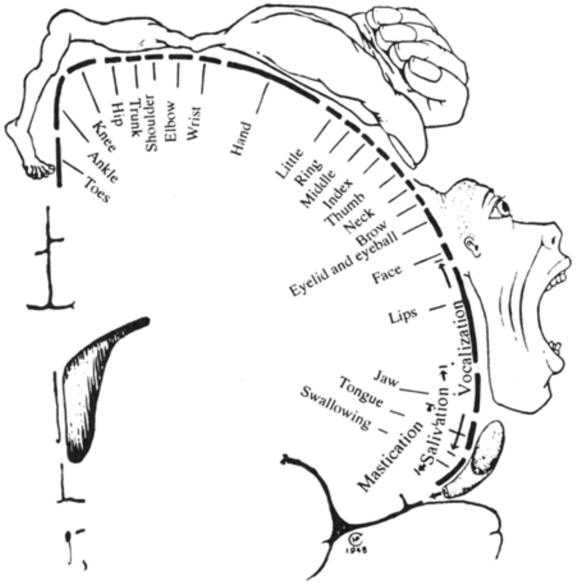

C5
T1


Motor neuron
Neuromuscular junction
Muscle fiber
Myelin
Schwann cell sheath
End-plate region
Axon
Presynaptic terminal boutons
Synaptic clefts
Mitochondria
Synaptic vesicle (ACh)
Dense bar (active zone)
Presynaptic membrane
Synaptic cleft
Postsynaptic membrane
ACh receptors
Basement membrane
Junctional fold

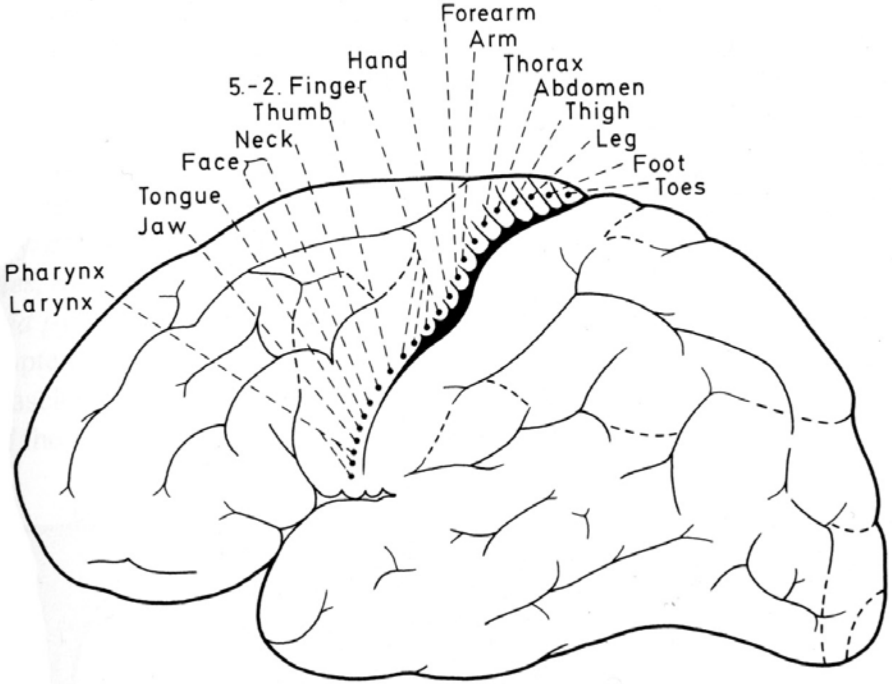

Flexors
Hand
Lower arm
Upper arm
Shoulder
Trunk
Extensors

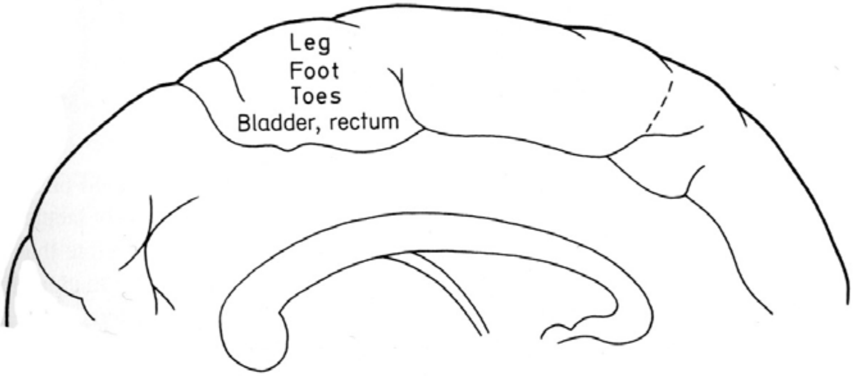

Basal ganglia:
Caudate nucleus
Putamen
Striatum
Globus pallidus
Subthalamic nucleus
Substantia nigra
Cerebrum
Cerebellum
Spinal cord
Deep cerebellar nuclei

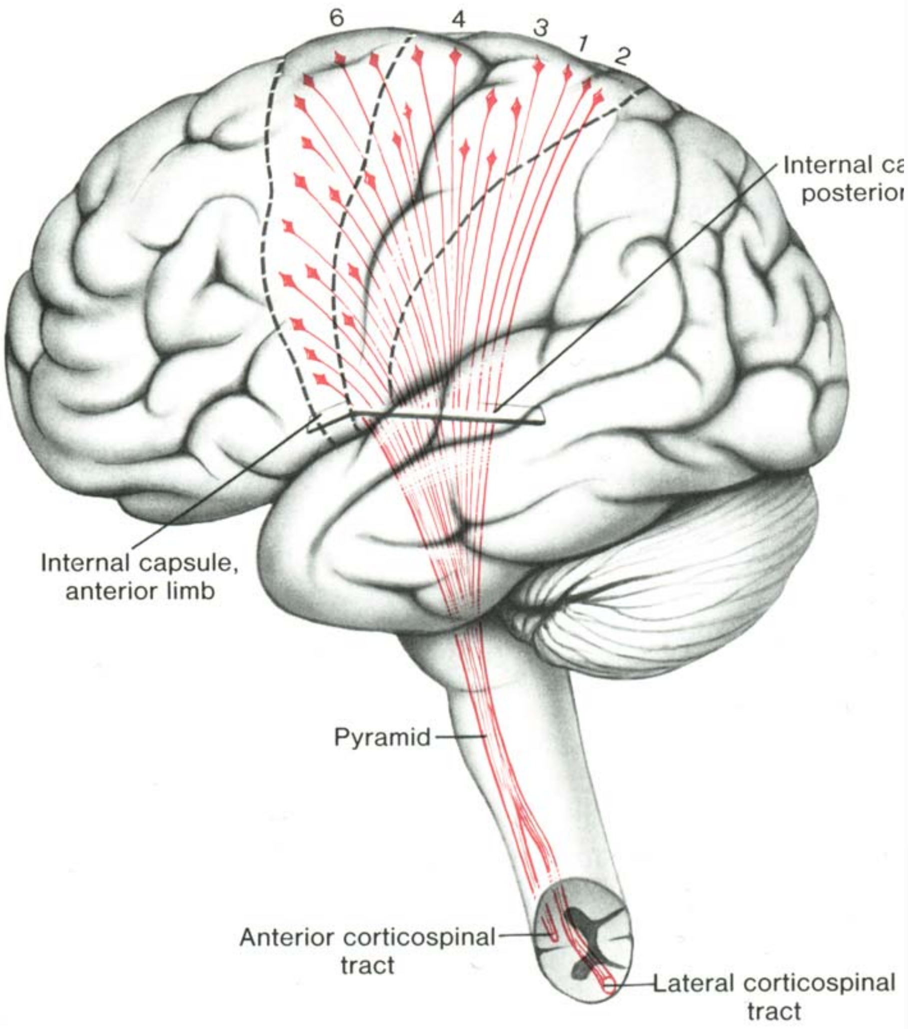

Area 6
Area 4
Posterior parietal cortex
SMA
PMC
M1
S1
Area 8
Area 5
Area 7
Prefrontal cortex
Posterior cingulate
Area 24

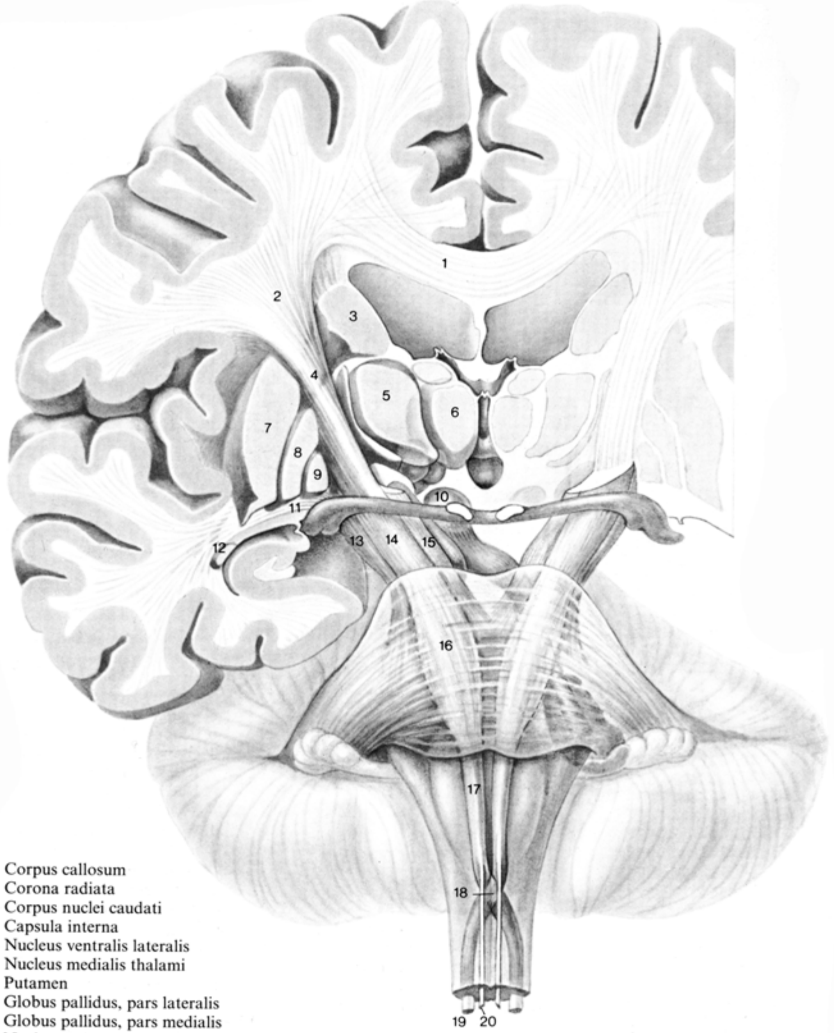

Toes
Ankle
Knee
Hip
Trunk
Shoulder
Elbow
Wrist
Hand
Little
Ring
Middle
Index
Thumb
Neck
Brow
Eyelid and eyeball
Face
Lips
Jaw
Tongue
Swallowing
Mastication
Salivation
Vocalization


Somatosensory cortex
Central sulcus
Motor cortex
3b
4
3a


Forearm
Arm
Hand
Thorax
Abdomen
5.-2. Finger
Thigh
Thumb
Leg
Neck
Foot
Face
Toes
Tongue
Jaw
Pharynx
Larynx

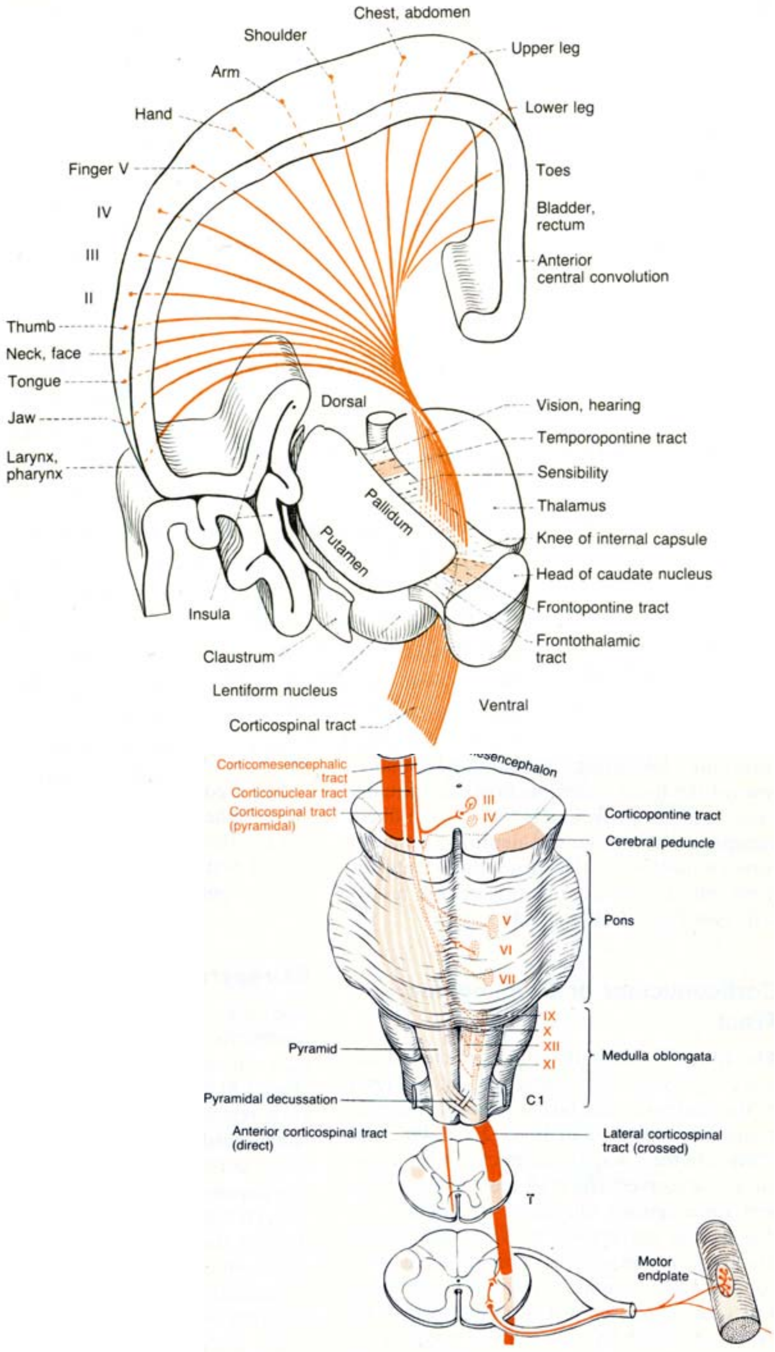

Leg
Foot
Toes
Bladder, rectum



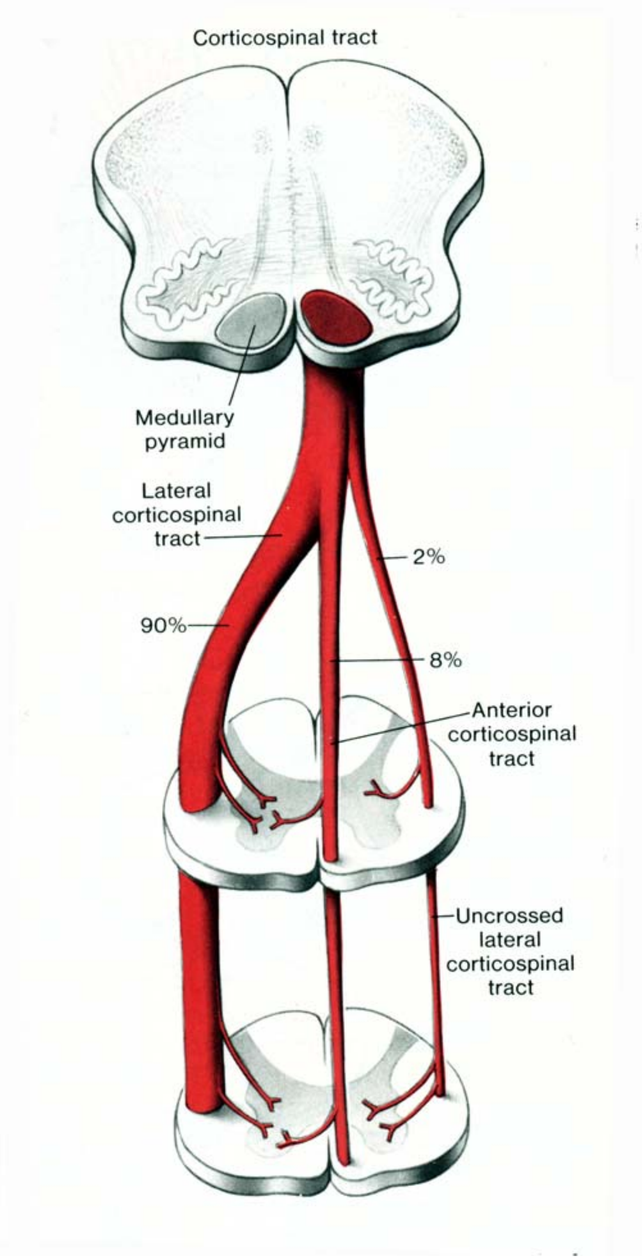


1 Corpus callosum
2 Corona radiata
3 Corpus nuclei caudati
4 Capsula interna
5 Nucleus ventralis lateralis
6 Nucleus medialis thalami
7 Putamen
8 Globus pallidus, pars lateralis
9 Globus pallidus, pars medialis
10 Nucleus ruber
11 Capsula interna, pars retrolentiformis
12 Cauda nuclei caudati
13 Tractus temporopontinus
14 Tractus pyramidalis } Pedunculus cerebri
15 Tractus frontopontinus

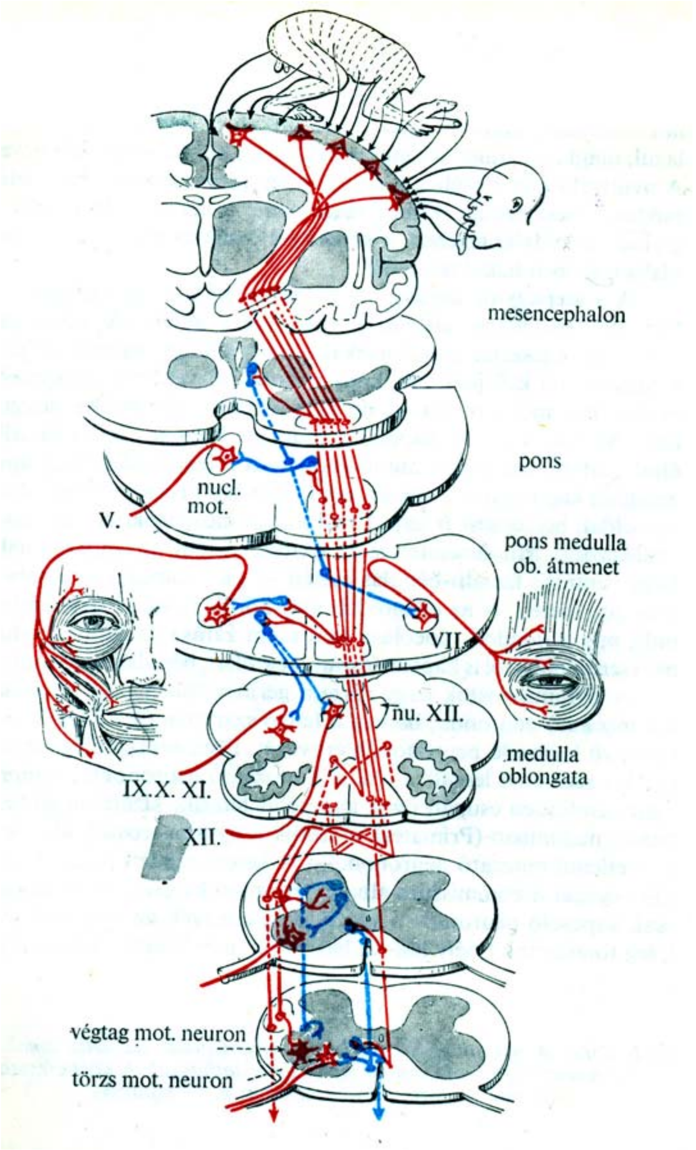
16 Pons
17 Pyramis
18 Decussatio pyramidum
19 Tractus pyramidalis lateralis
20 Tractus pyramidalis anterior

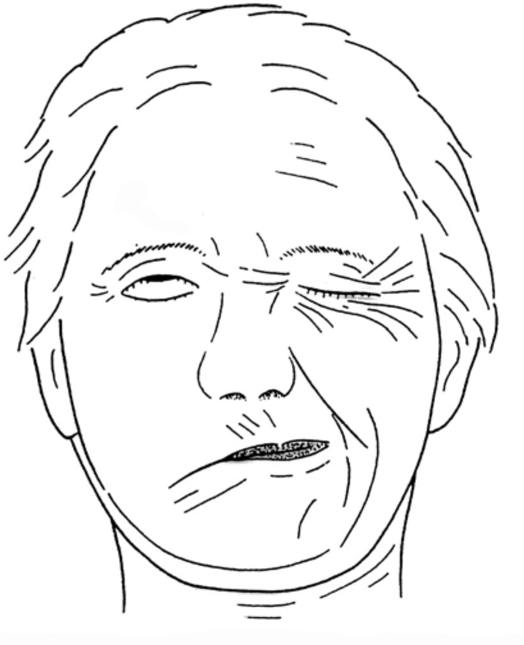


Chest, abdomen
Shoulder
Upper leg
Arm
Hand
Lower leg
Finger V
Toes
IV
Bladder, rectum
III
Anterior central convolution
II
Thumb
Neck, face
Tongue
Jaw
Larynx, pharynx
Dorsal
Vision, hearing
Temporopontine tract
Sensibility
Pallidum
Thalamus
Putamen
Knee of internal capsule
Head of caudate nucleus
Insula
Frontopontine tract
Frontothalamic tract
Claustrum
Lentiform nucleus
Ventral
Corticospinal tract
sencephalon
Corticomesencephalic tract
Corticonuclear tract
III
Corticospinal tract (pyramidal)
IV
Corticopontine tract
Cerebral peduncle
V
Pons
VI
VII
IX
X
Pyramid
XII
Medulla oblongata
XI
Pyramidal decussation
C1
Anterior corticospinal tract (direct)
Lateral corticospinal tract (crossed)
T
Motor endplate

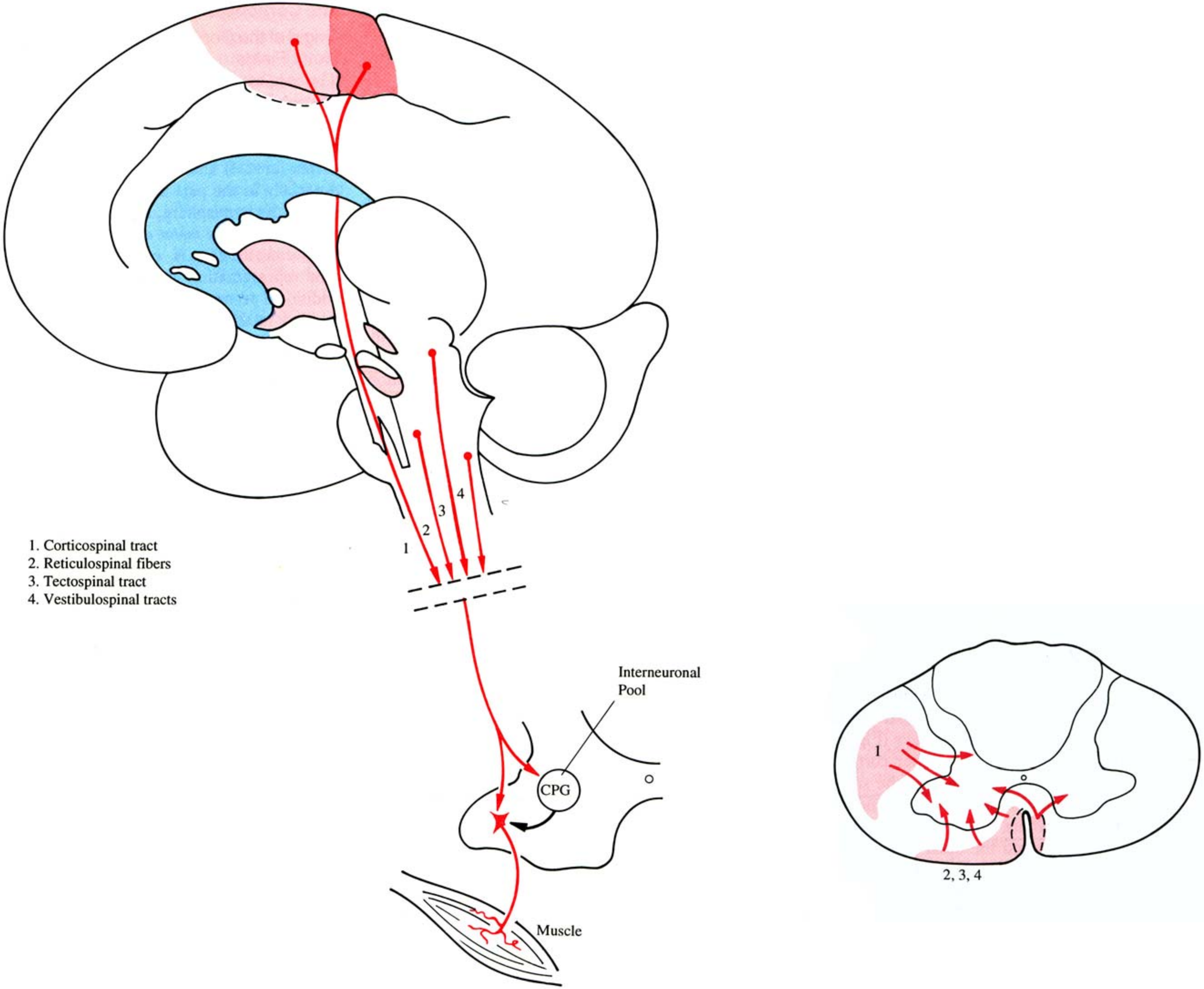


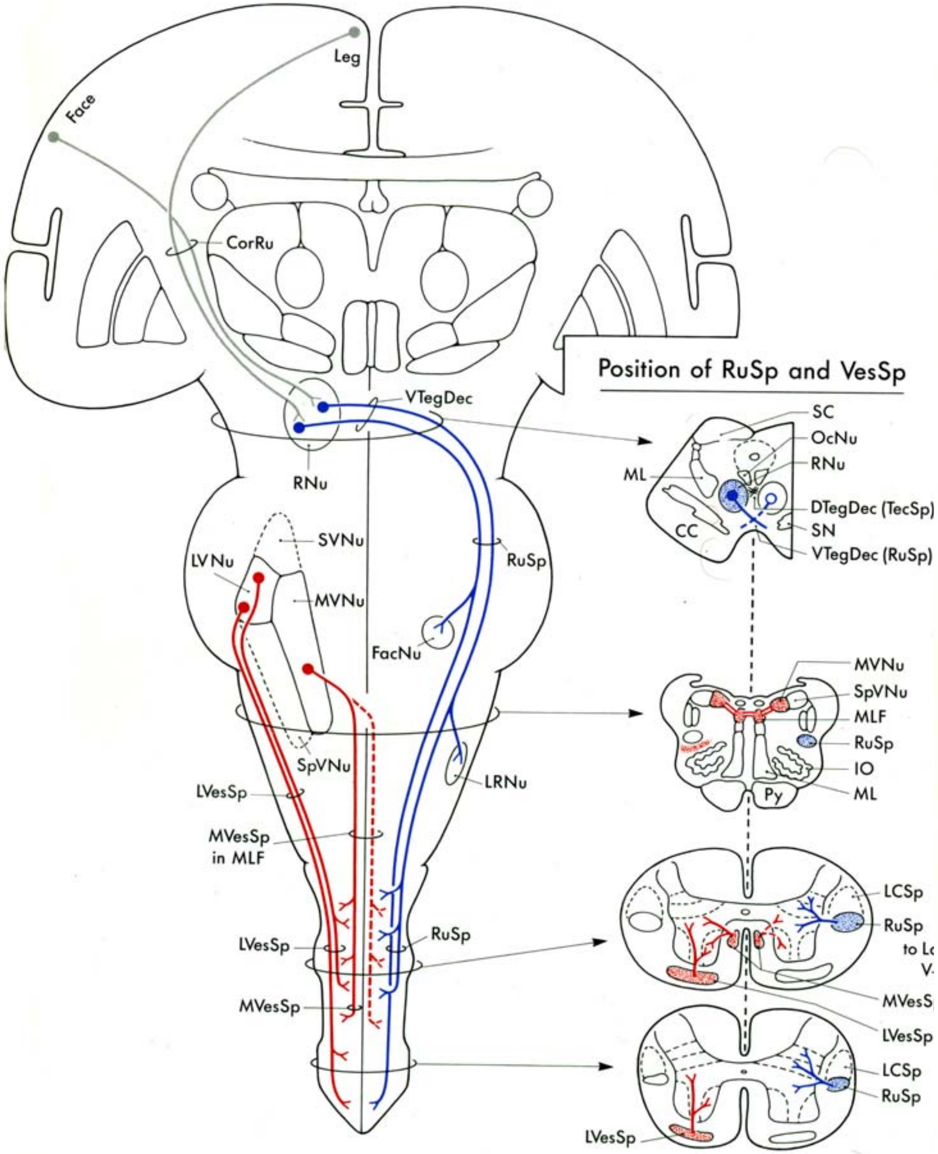
Corticospinal tract
Medullary pyramid
Lateral corticospinal tract
2%
90%
8%
Anterior corticospinal tract
Uncrossed lateral corticospinal tract

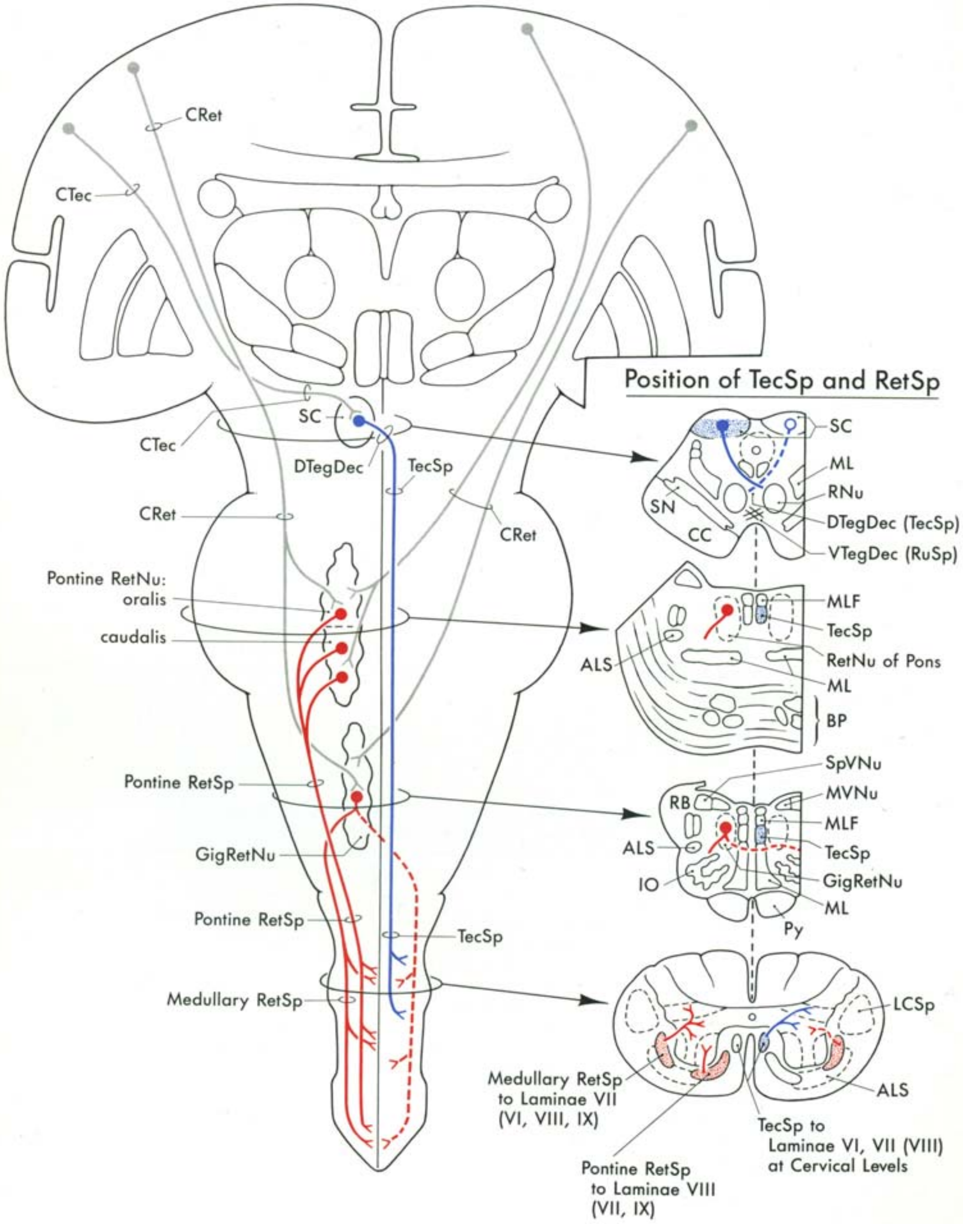




Peripheral facial paralysis (right side). The patient is asked to close her eyes and to retract their mouth (From Heimer)

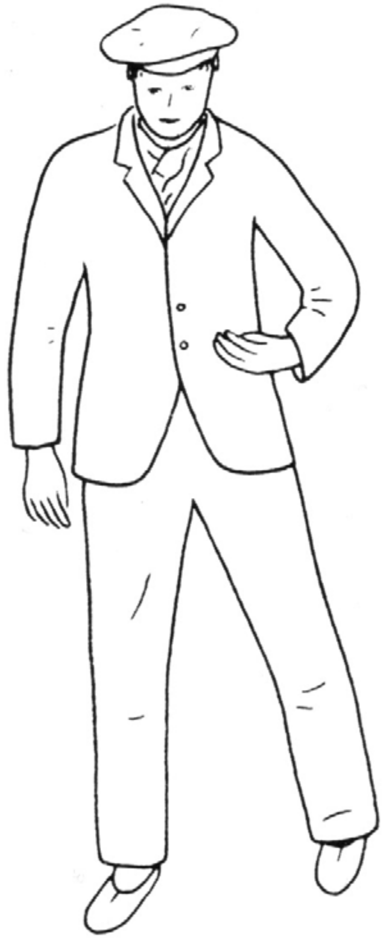

1. Corticospinal tract
2. Reticulospinal fibers
3. Tectospinal tract
4. Vestibulospinal tracts
1
2
3
4
Interneuronal Pool
CPG
Muscle
1
2, 3, 4


Position of RuSp and VesSp

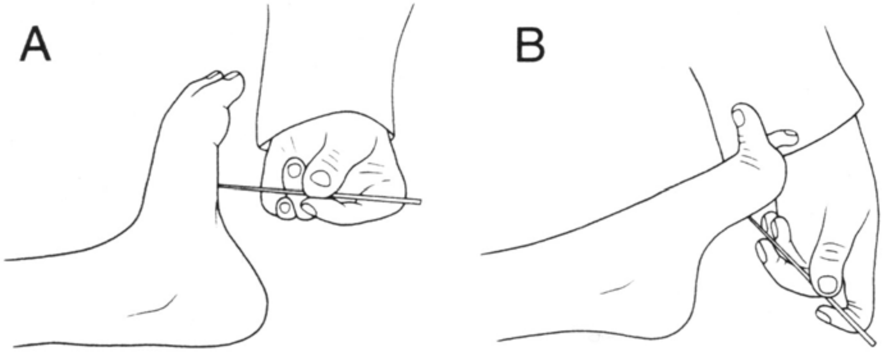

Position of TecSp and RetSp

EXTRAPYRAMYDAL DESCENDING PATHWAYS

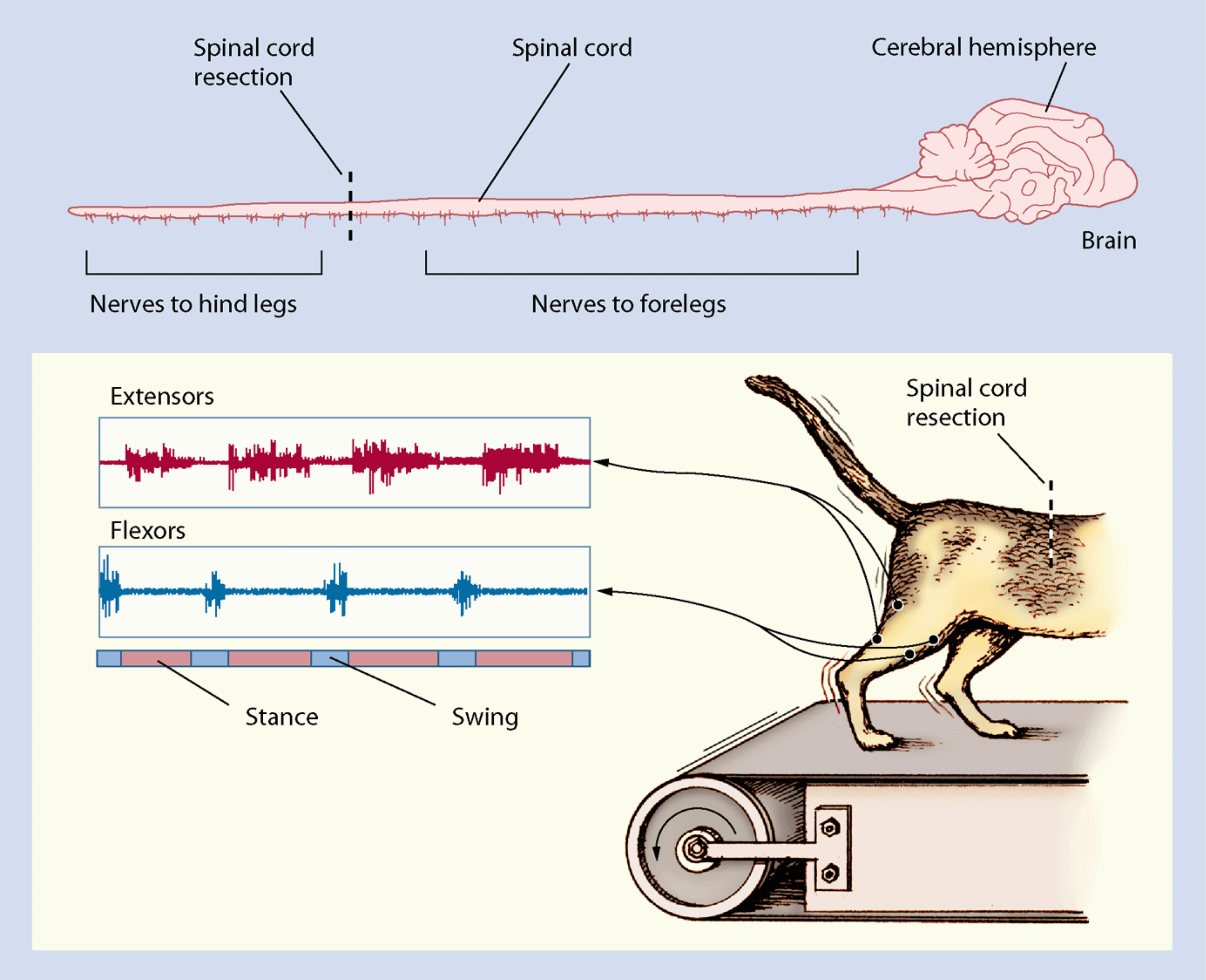
Cortical input	**Pathway**	**Function**
yes	Rubrospinal	voluntary distal movement
yes	Reticulospinal	crude voluntary, axial proximal
yes	Tectospinal	orienting, saccadic eye movement
no	Vestibulospinal	axial, proximal musc, reflex head movements in response to vestibular stimulation



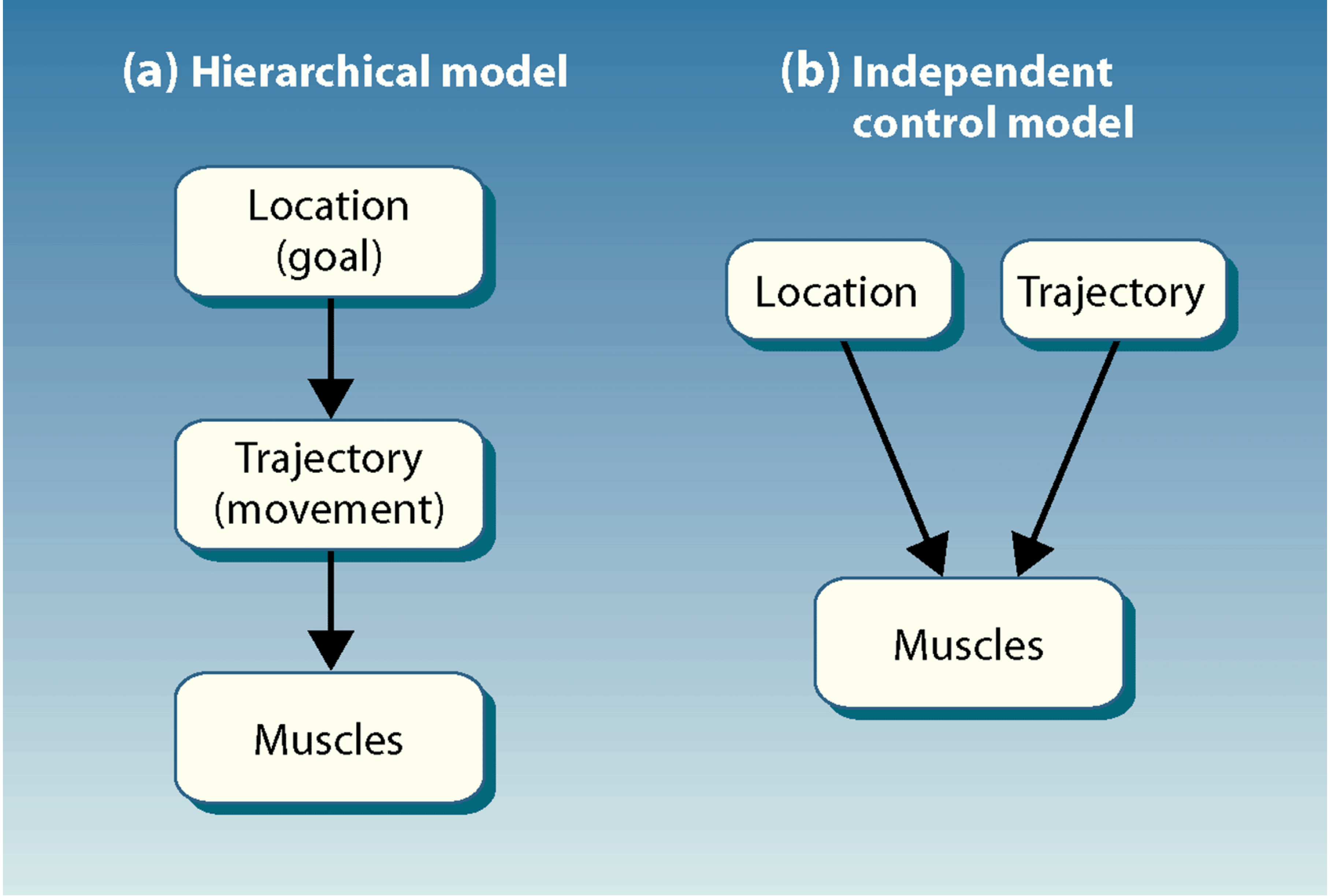
Hemiplegia of the left side. Note the characteristic position of the arm with flexion in the elbow and wrist. The paretic leg is moved laterally in a semicircle during the swing phase to keep the foot of the ground (circumduction) (From Brodal)



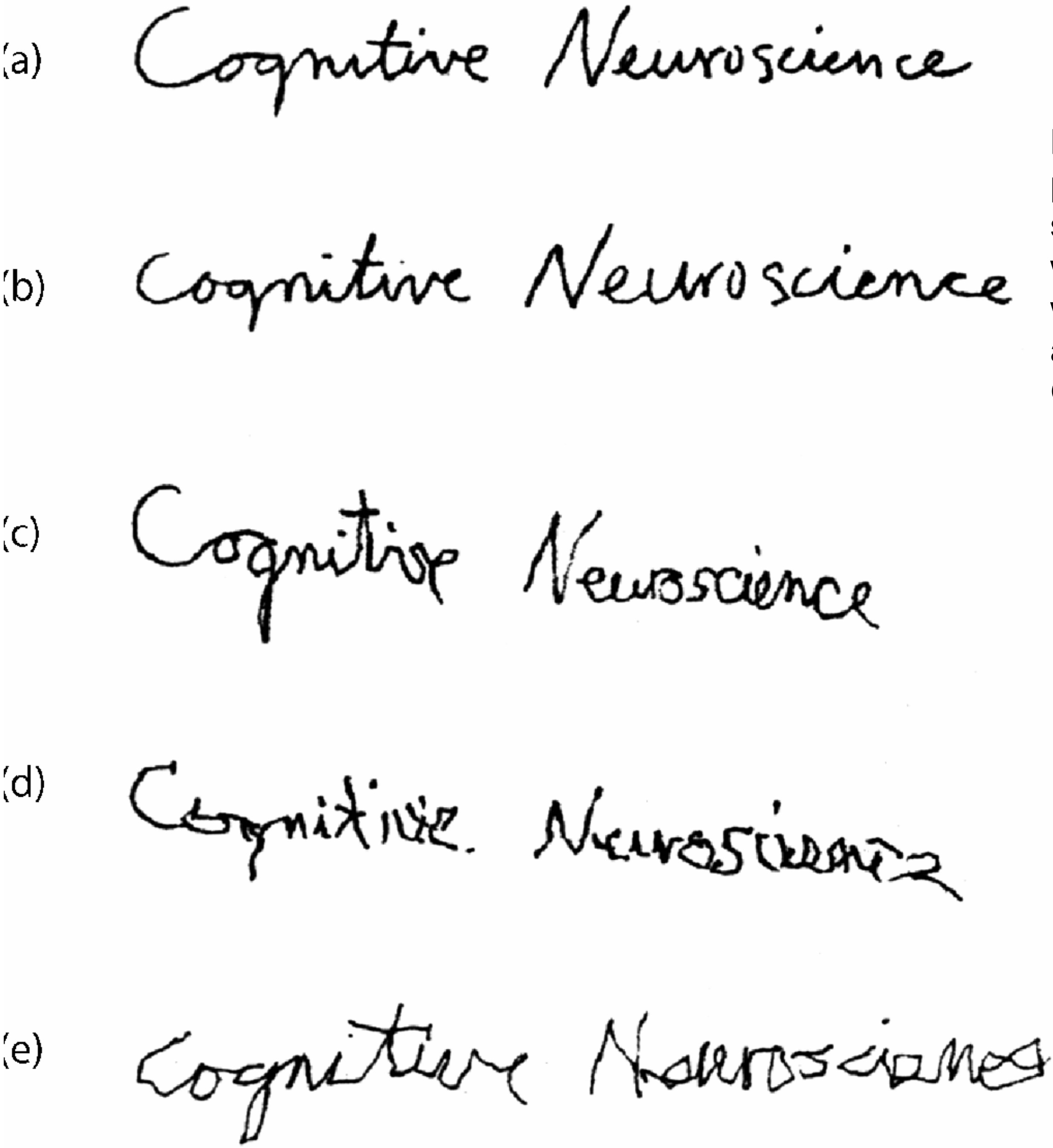
Inverted plantar reflex in central paresis (Babinski. A: normal. B: in a patient with damage of the pyramidal tract the big toe moves upward (dorsiflexion) (From Brodal)



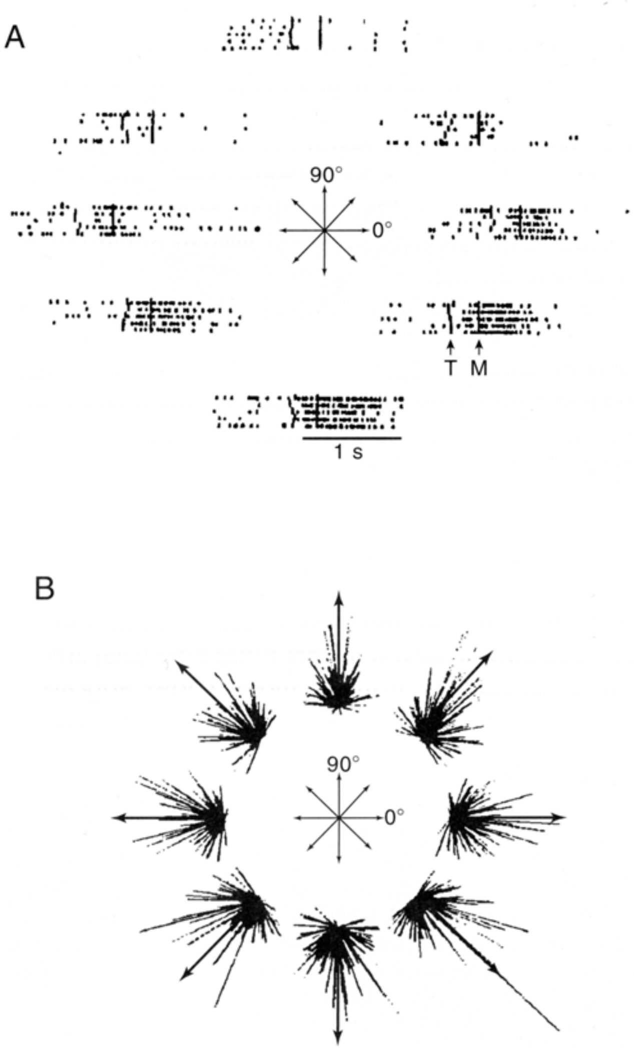
In Brown’s classic experiment, the spinal cord was severed so that the nerves to the hind legs were isolated from the brain. The cats were still able to produce stereotypic rhythmic movements with the hind legs when walking on a moving treadmill. Since all inputs from the brain were eliminated, the motor commands must have originated in the lower portion of the spinal cord.



Location and trajectory planning of motor commands. (a) in the hierarchical model, goals are specified initially as target locations. A translation process is then required to determine the trajectory and corresponding muscle activity required to move a limb to the goal. (b) An alternate hypothesis is that location and trajectory planning provide two different representations for determining muscle activity (From Gazzaniga).

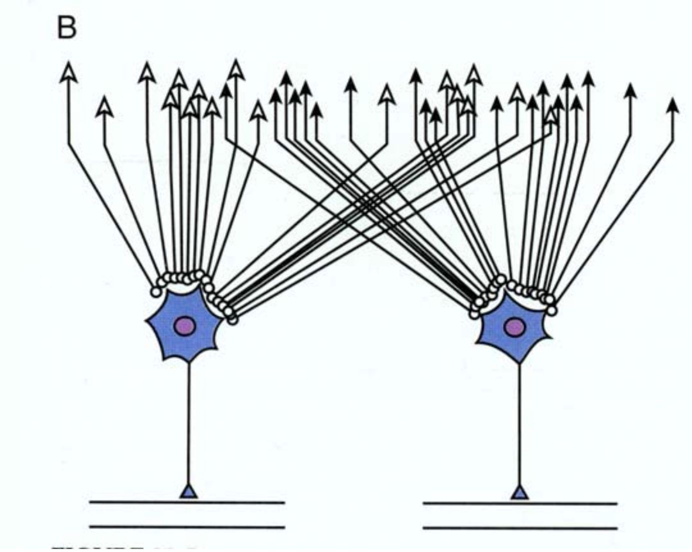


Motor representations are not linked to particular effector system. These scripts were produced by moving a pen with (a) the right hand, (b) the right wrist, (c) the left hand, (d) the mouth, and (e) the right foot. (From Gazzaniga)

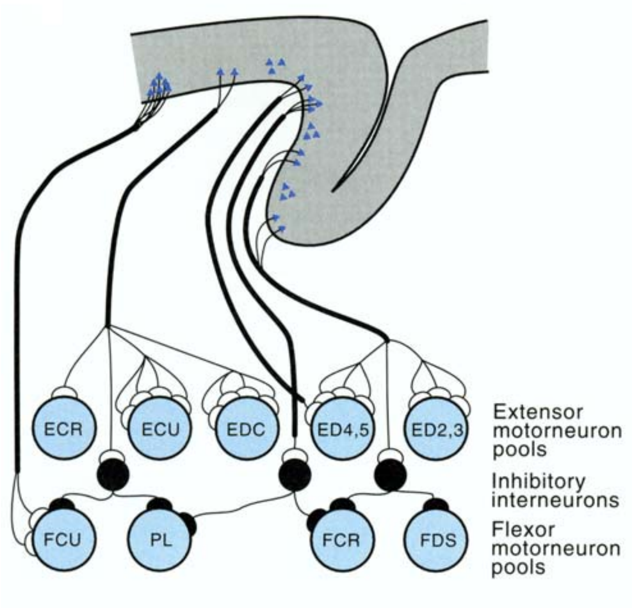


Motor cortex activity is correlated with movement direction. A The animal was trained to move a lever from the center location to one of 8 locations. The activity of motor cortex neuron is plotted next to each target location. Each row represent a single movement and the dots correspond to action potentials. The eight rasters show that this neuron’s activity was related to movements in four of the 8 directions. The neuron discharged most intensely for movements down and to the right and was inhibited during movements up and to the left. B: For each of the 8 movements the discharge of each M1 neuron is shown as a line pointing in the neuron’s preferred direction. Each line starts at the movement endpoint, and its length is proportional to the intensity of the discharge of that neuron during movement in that direction. Although the discharge of single neurons rarely identified ant single movement direction with accuracy the population vectors (arrows) summing the discharge of an ensemble of M1 neurons adequately specify each of the 8 movement directions. (Georgopoulos)

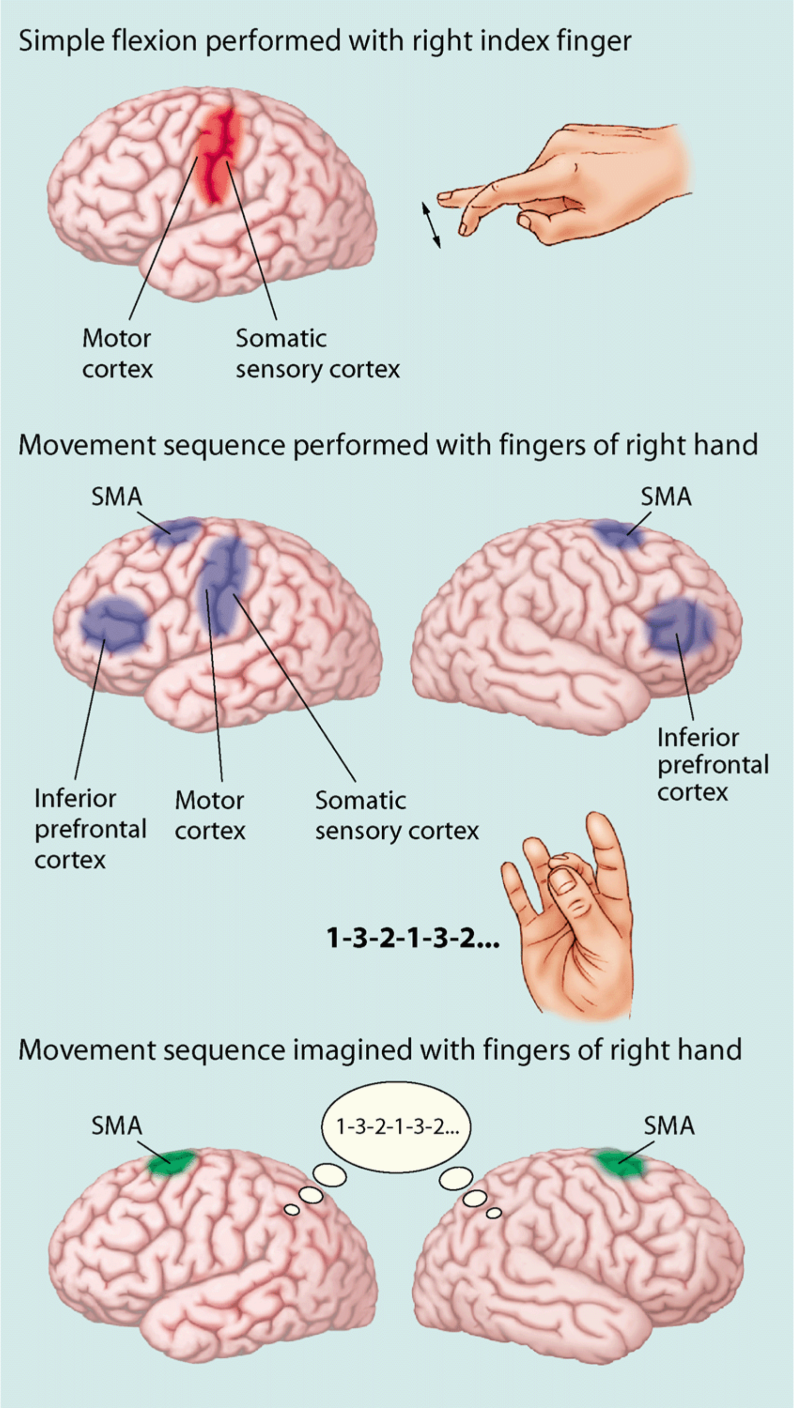
A



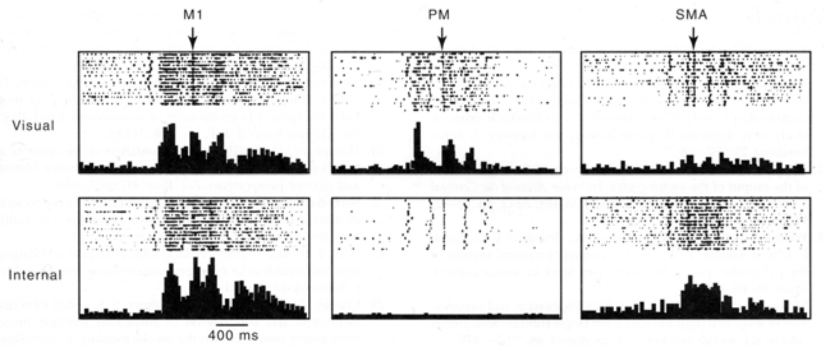
C



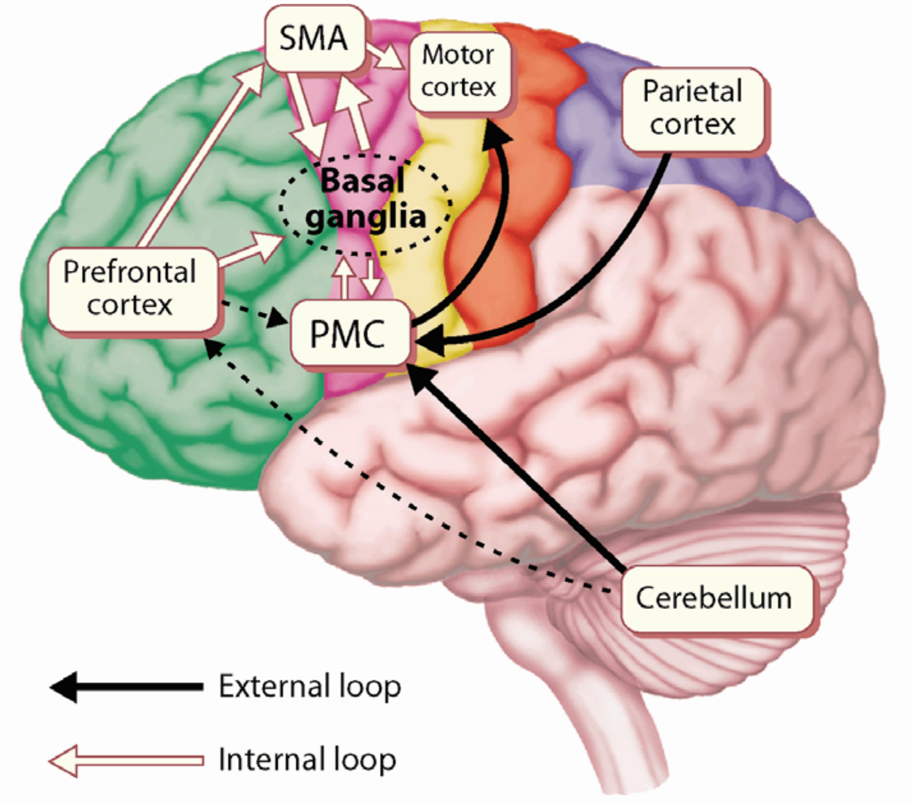
A: Divergence of M1outputs to multiple muscles. Tracing of a single corticospinal axon ramifying in the ventral horn of the spinal cord shows terminal fields in the motor neuron pools of four foerearm muscles (Shinoda et al). C: Output of single corticospinal neurons often diverges to influence multiple muscles (Cheney et al). B: Convergence of M1 outputs to single muscles. The cortical input to any muscle's motor neurons originates from a wide territory in M1 and that the cortical territory provifing input to other muscle overlaps extensively with the cortical territory providing input to other muscles in the same part of the body (Anderson).



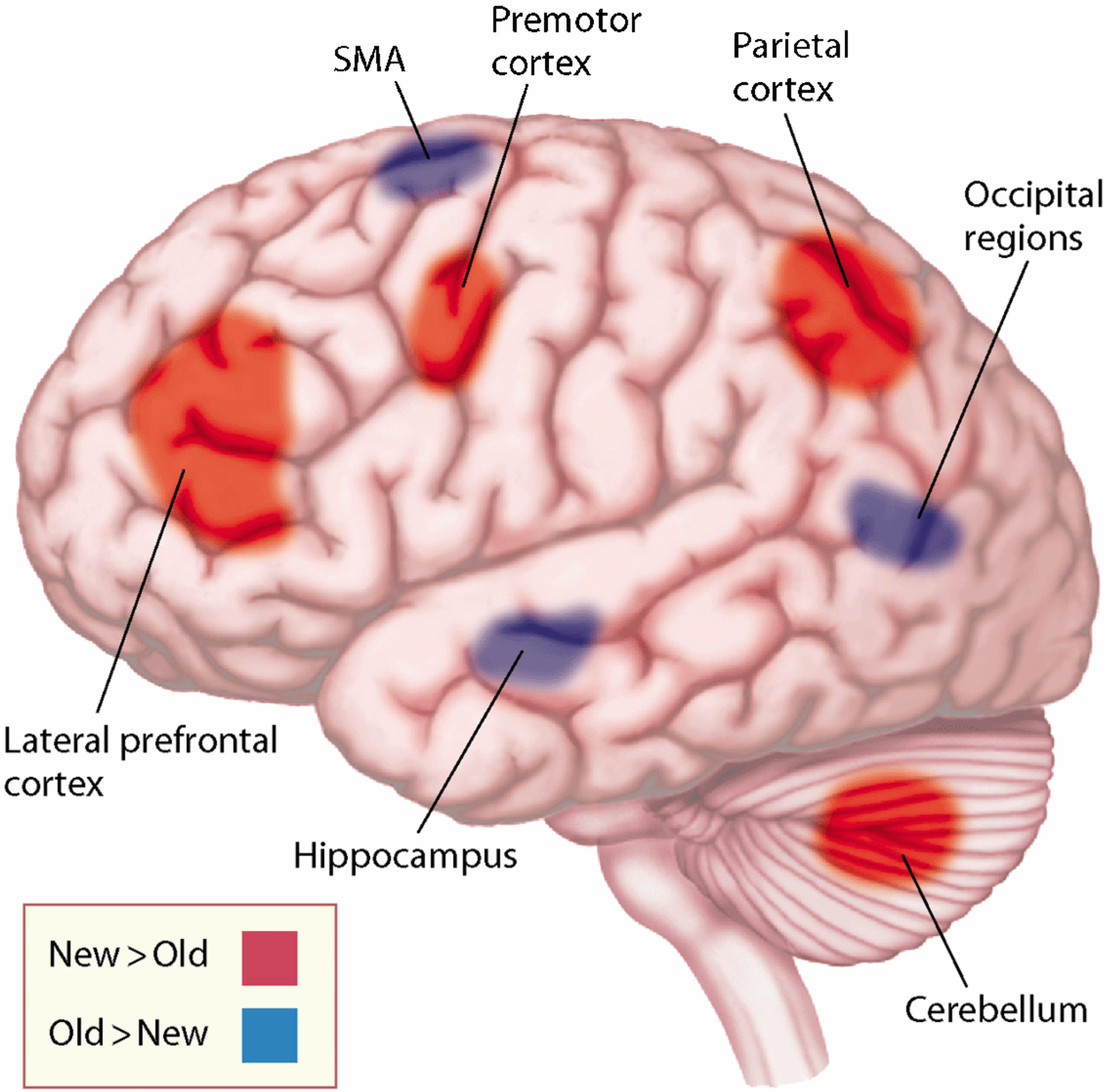
Areas of metabolic activity associated with a variety of motor tasks. Blood flow increases were restricted to primary motor and somatic sensory cortical regions in the contralateral hemisphere during simple flexions and extension of the index finger of the right hand. When the subjects were asked to perform a complicated series of sequential finger movements with the right hand, blood flow increases also were observed bilaterally in the SMA and prefrontal areas. The SMA was also active, bilaterally, when the sequence was mentally rehearsed. During this imagery condition, no increases were present in M1 (Roland, 1993; Gazzaniga et al., 2002).



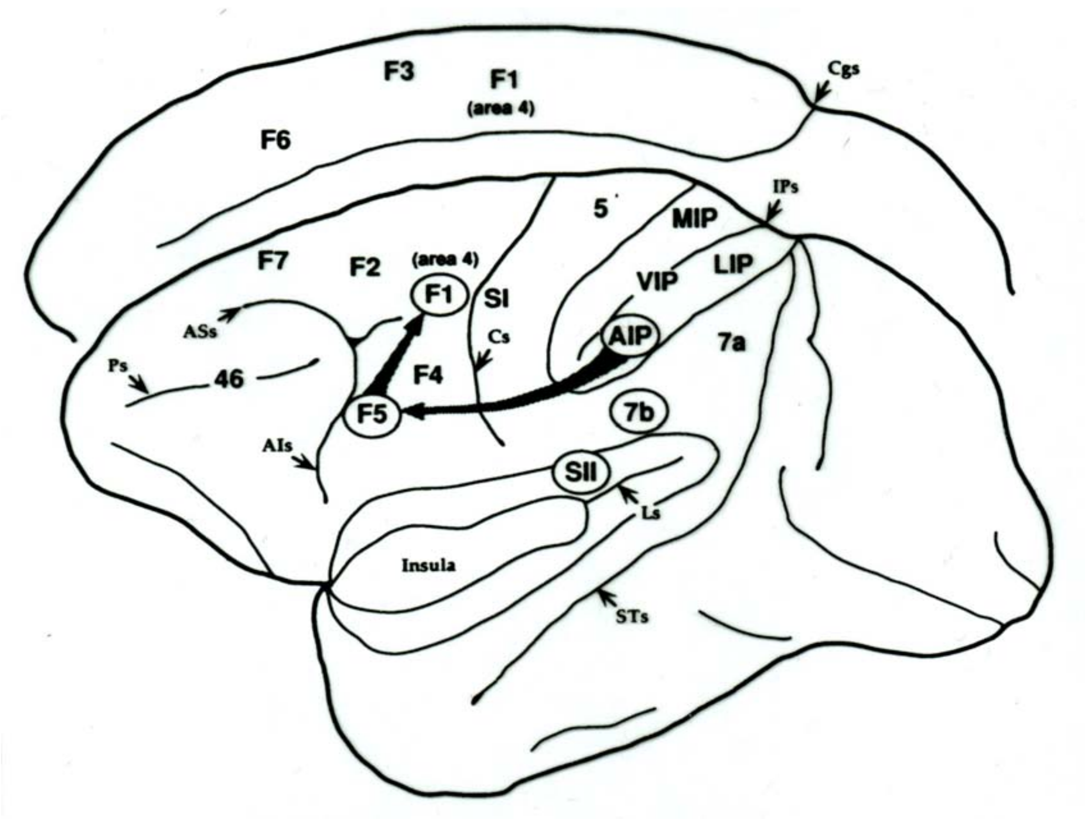
Activity of 3 neurons, - one in M1, one in PM and one in SMA- recorded as a monkey pressed 3 boutons in sequence. The sequence was first visually cued by lighting the buttons and then internally cued. The M1 neuron showed similar activity whether the monkey performed from visual or internal cues. The PM neuron, however, was much more active in response to visual than internal cues, while the opposite was true for SMA neuron (Mushiake et al., 1991).



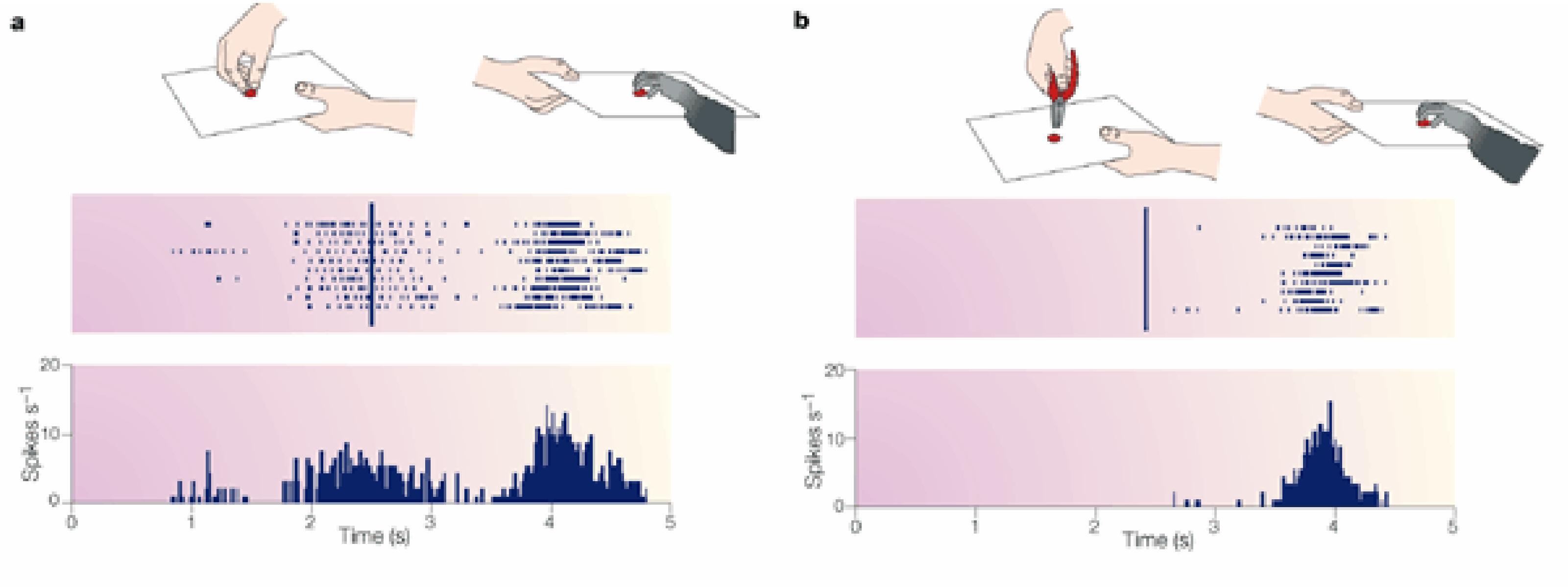
Movements may vary in terms of the contribution of internal and external sources of information. The external loop, including the cerebellum, parietal lobe, and lateral premotor cortex (PMC) dominates during visually guided movements. The internal loop, including the basal ganglia and SMA, dominate during self-guided, well learned movements (Gazzaniga et al., 2002).



Shifts in metabolic activity during motor learning. PET scans were obtained under two conditions: while subjects performed a well-learned movement sequence (Old) and during the course of learning of a movement sequence (New). Learning was associated with blood flow increases in lateral premotor and prefrontal areas; in contrast, performance of previously learned sequences was correlated with blood flow increases in SMA and hippocampus (Jenkins et al., 1994; Gazzaniga et al., 2002).



Lateral and medial views of the monkey cerebral cortex. The visuomotor stream for grasping is indicated by large arrows. F5 also receives somatosensory input from areas SII, and somatosensory and visual input from area 7b (circled areas). Cortical areas that control grasping are connected with basal ganglia and cerebellar circuits (not shown). AIP= anterior intarparietal area; VIP= ventral intarparietal area; MIP= medial intraparietal area; LIP= lateral intraparietal area; STs= superior temporal sulcus; Cs=central sulcus; AIs; ASs= inferior, superior arcuate sulcus (Jedannerod et al., 1995)



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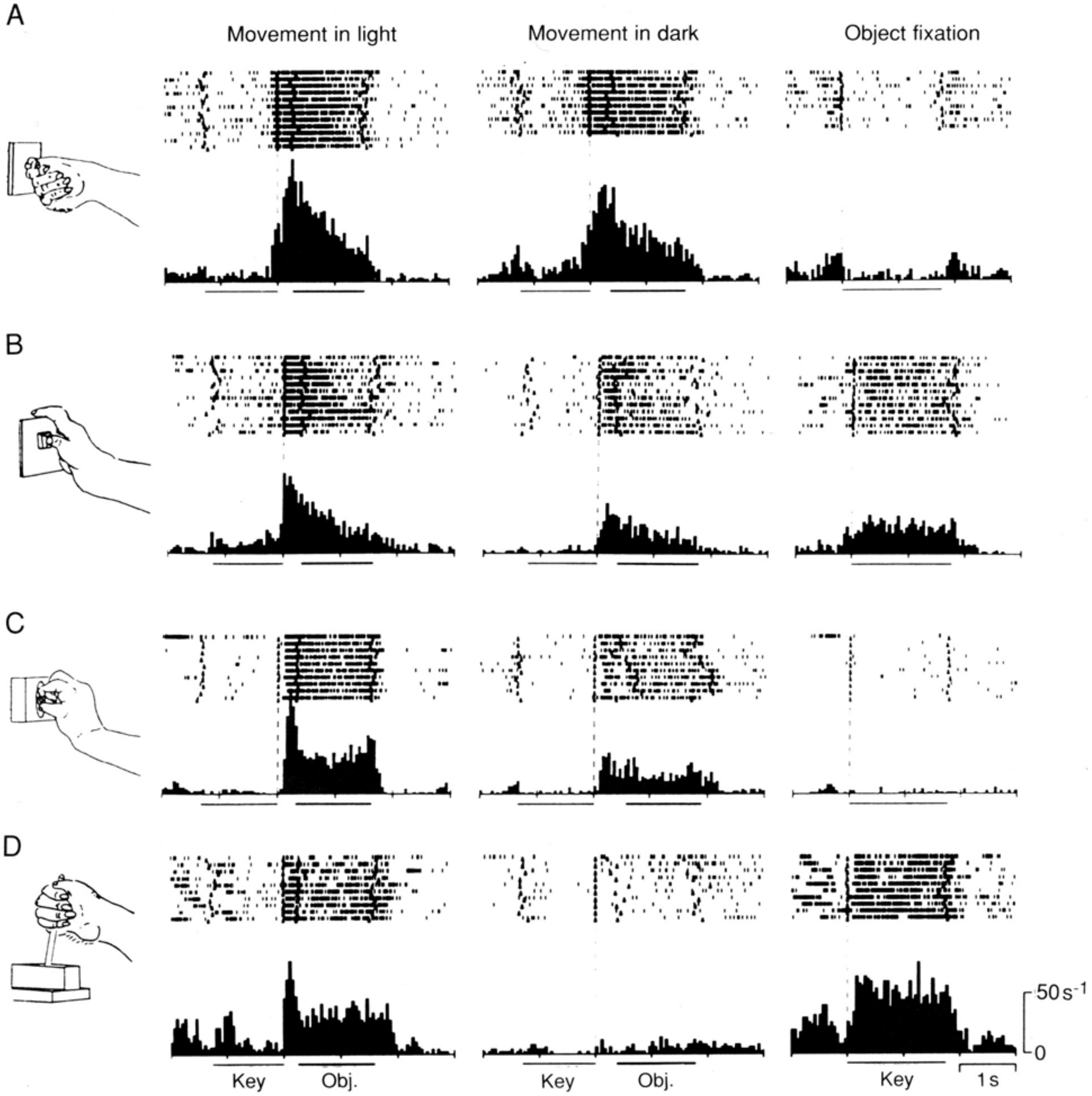
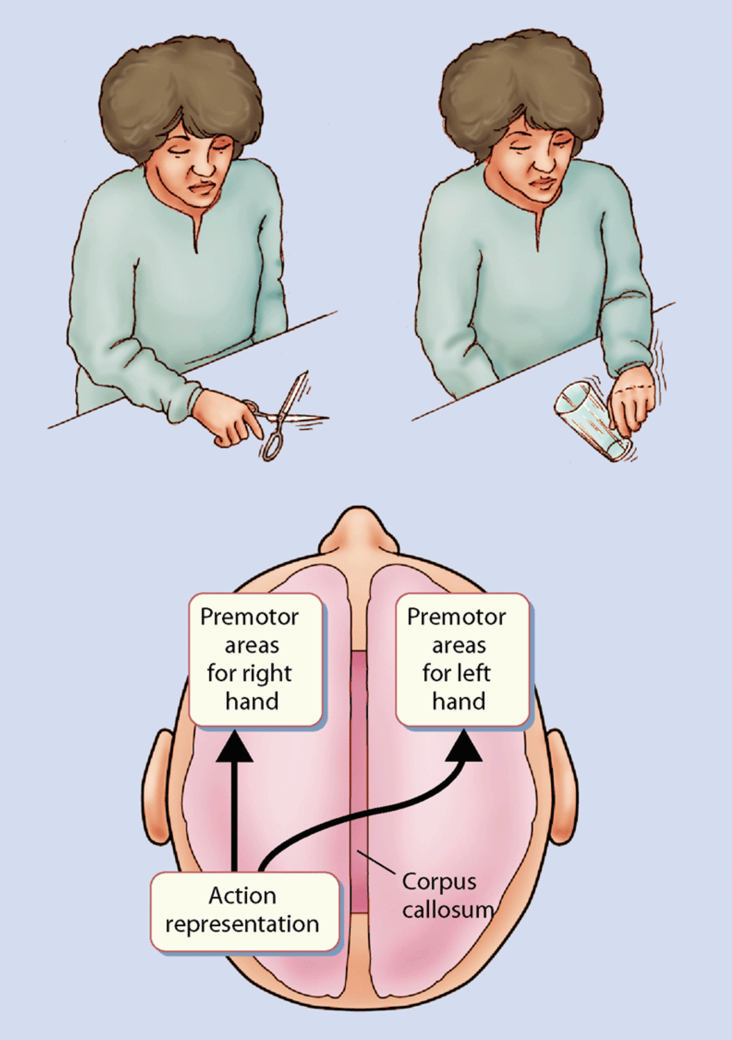
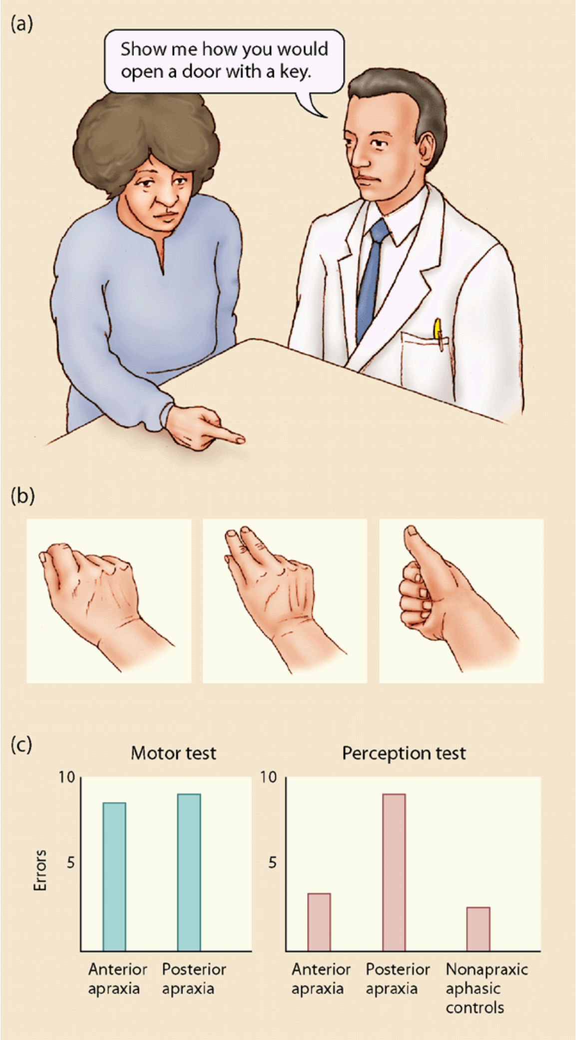
Visual and motor responses of a mirror neuron in area F5. **a** | A piece of food is placed on a tray and presented to the monkey. The experimenter grasps the food, then moves the tray with the food towards the monkey. Strong activation is present in F5 during observation of the experimenter's grasping movements, and while the same action is performed by the monkey. Note that the neural discharge (lower panel) is absent when the food is presented and moved towards the monkey. **b** | A similar experimental condition, except that the experimenter grasps the food with pliers. Note the absence of a neural response when the observed action is performed with a tool. Rasters and histograms show activity before and after the point at which the experimenter touched the food (vertical bar). Rizzolatti et al., 2001



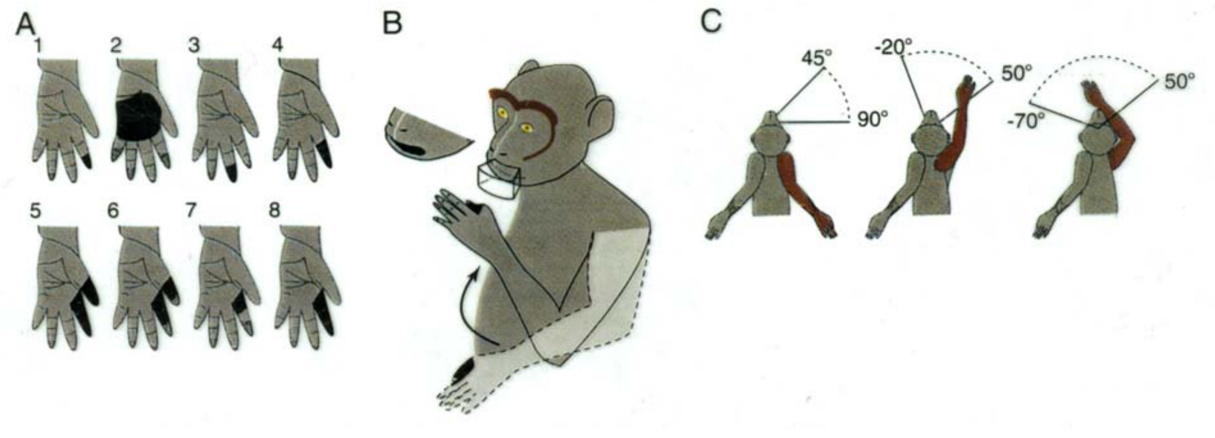
Types of neurons in monkey intarparietal area (AIP) that are involved in hand manipulation. Activity of cells during hand manipulation in light and in dark, as well as during visual fixation objects, is shown with rasters and histograms. Key indicates the period of pressing the anchor key before moving to the object. Obj. indicates the period of holding the object to keep the switch on (Jeannerod et al., 1995)



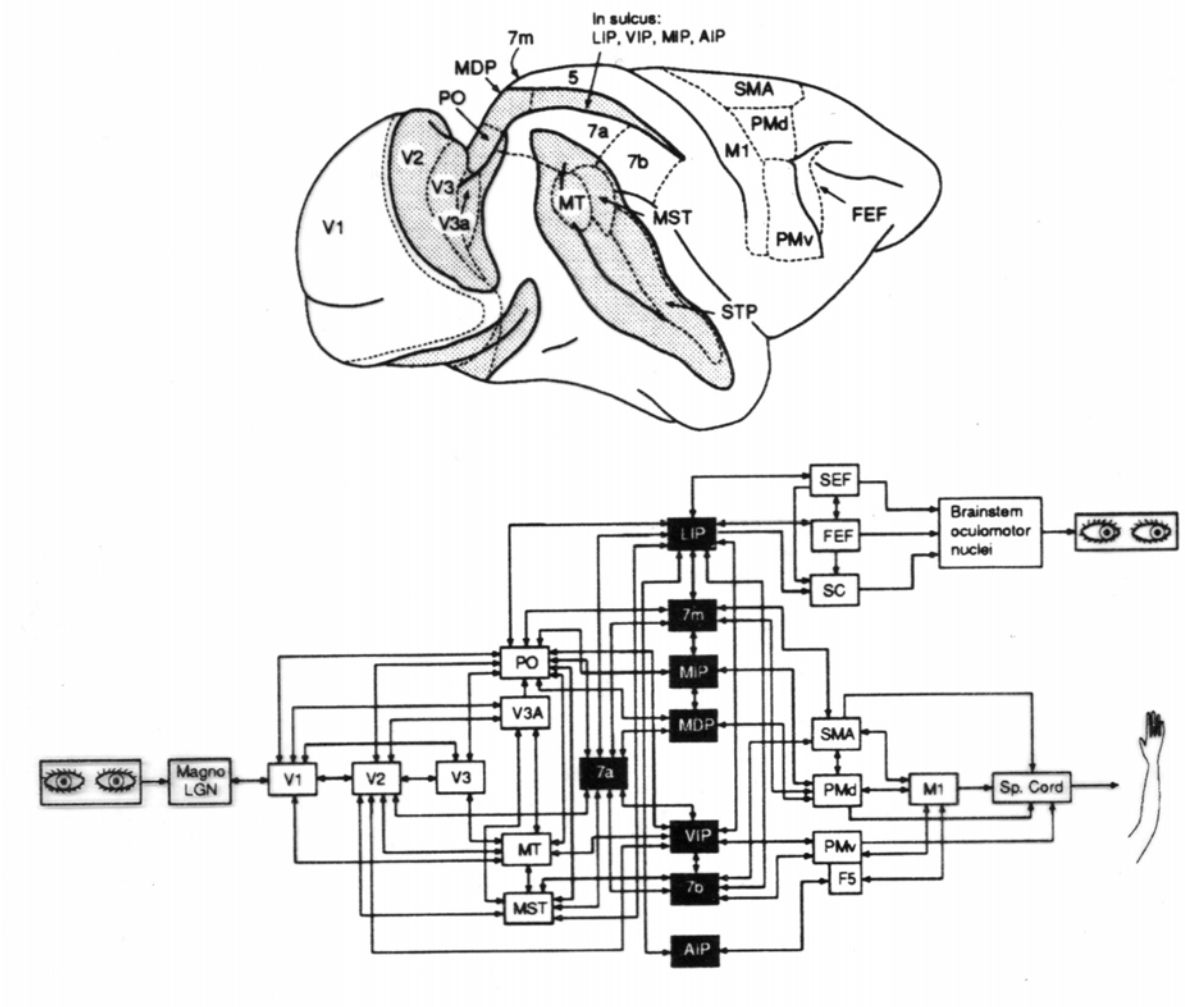
Model of the neural regions associated with the production of skilled actions. The premotor area of the contrlateral hemisphere are essential for skilled movements of the limbs. These areas receive input from the parietal lobe of the left hemisphere, an area, assumed to store the representations of the actions. Thus, a lesion in the posterior parietal area will lead to apraxic movements with both contra-and ipsilesional limbs (Gazzaniga et al., 2002).



(a): Motor; (b) perception test. (c): Patients with either anterior or posterior lesions who produced apraxic gestures on the motor task were selected. Only the patients with posterior lesions showed impairment on the perception test. The apraxic patients with anterior lesions performed as well as nonapraxic (Heilman et al., 1982; Gazzaniga).



Sensory receptive fields in M1and PMv A: Black regions show the tactile receptive fields of 8 M1 neurons recorded at loci where intaqrcortical microstimulation evoked flexion of the monkey’s index and ring fingers. Other neurons at the same loci responded to passive extension of those fingers (Rosen and Asanuma). **B**: A single PMv neuron responded to visual stimuli moving near the mouth, to tactile stimulation of the lips and the skin between the thumb and index finger, and to flexion of the elbow. C: Another PMv neuron with a tactile receptive field covering the entire right arm had a visual receptive field for objects moving near the face. The visual receptive field shifted from right to left as the right arm was moved from right to left (Graziano et al).



Visuomotor pathways of the monkey brain. (a) Lateral view of macaque cerebraql cortex ahowing some of the cortical areas involved in the representation of visual space and visuomotor coordination. Major posterior sulci have been opened up to show the buried cortex (shaded areas). (b) Some of the neural pathways by which visual information entering the eye might guide movement of the eyes and limbs. Areas shown in black are in the posterior parietal lobe. FEF=frontal eye field; LGN= lateral geniculate body (Gross: in Current Opinion in Neurobiology)

Cortex	**Input**	**Output**	**Function**
M1	VL,S1, par 5,6, PM	Brainstem Basal ganglia Red nucleus Reticular Formation (RF) Pyramidal tract	distal part of extremities, face
M2 or Supplementary Motor Area (SMA)	frontal,parietal, temp amygdala VA/VL	M1 RF Pyramidal tract (prox.limb)	Planning, initiation of complex movement, dominates when task is internally generated, previously learned sequences; bimanual coordination
Premotor (PM)	extrastriate, Par 5,7 VA/VL	M1 Basal ganglia few to pyramidal mRF-proximal limb, intralimb coord.	Tactile, auditory and visually guided movements, proper orientation of the hand and fingers when they approach an object to be grasped; developing new skills
Parietal 5,7		PM	goal directed reaching movement, exploratory hand mov, learned movement