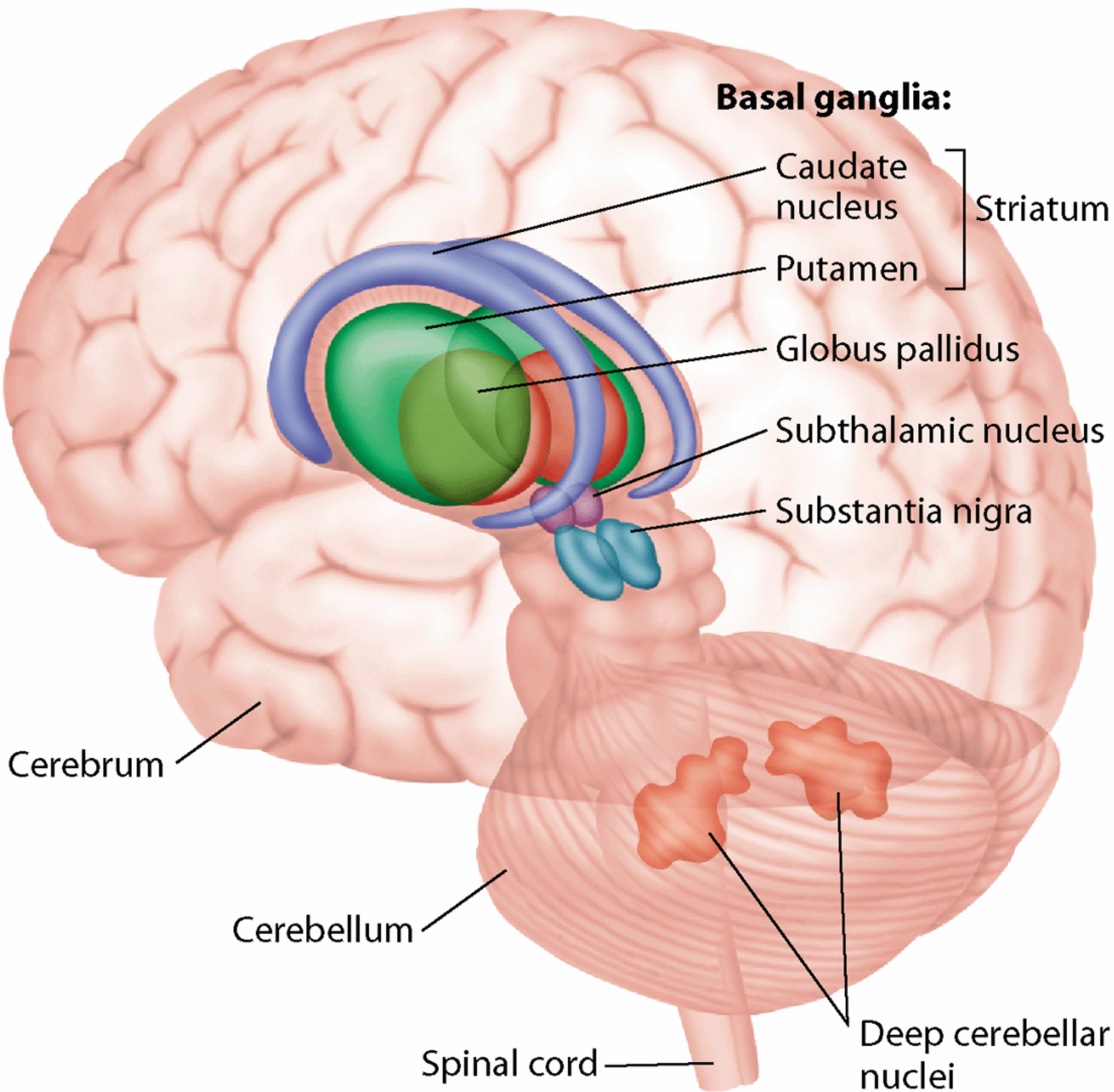
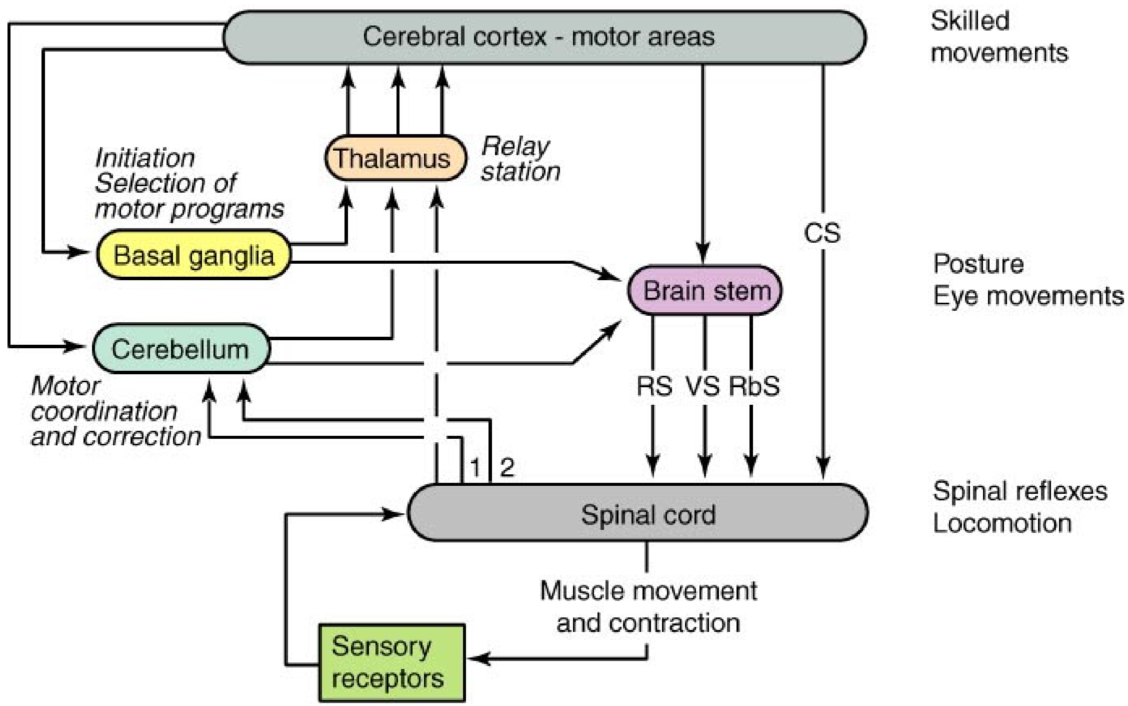
MOTOR SYSTEMS



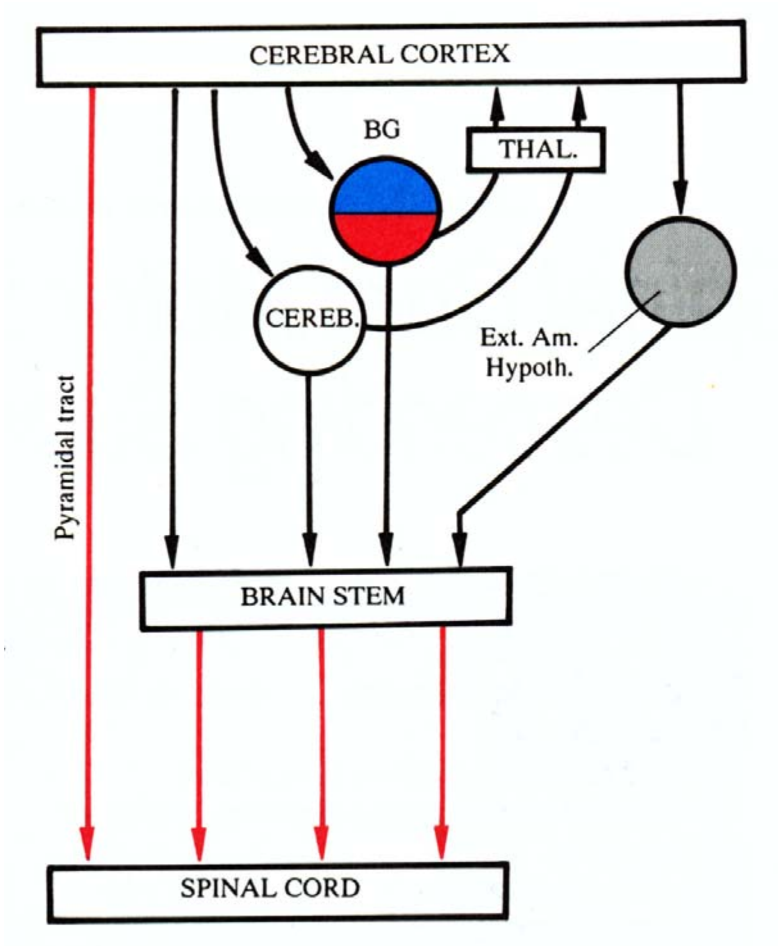


Basic functions of descending tracts

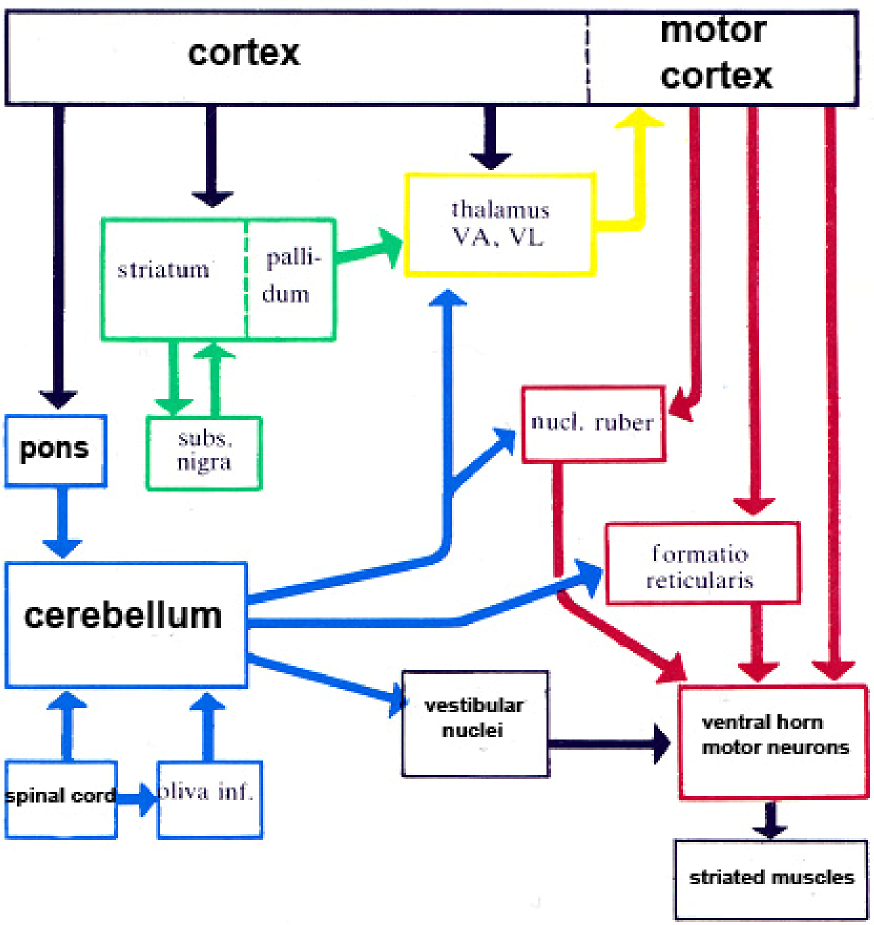
Cortico- and rubrospinal
1. Transmission of commands for skilled movements.
2. Corrections of motor patterns generated by the spinal cord.

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

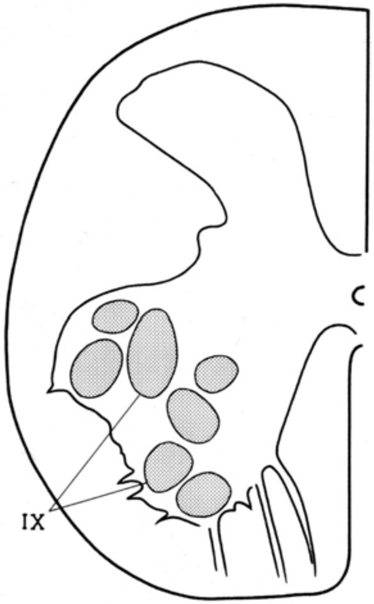


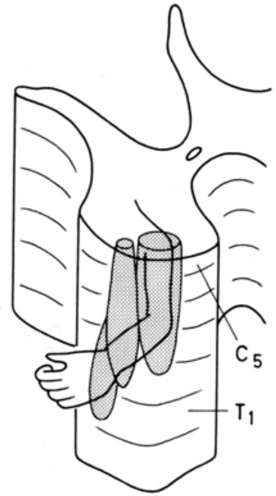
Heimer

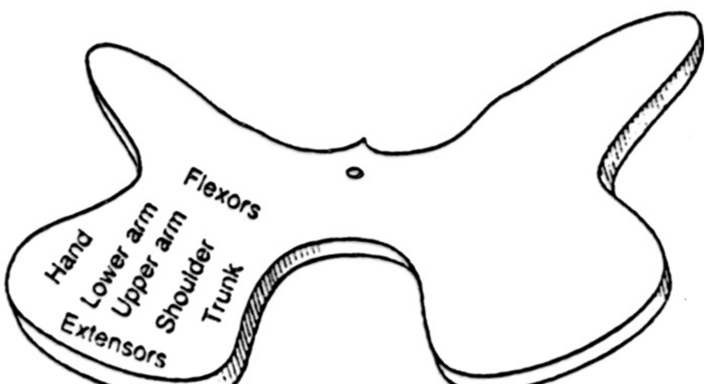


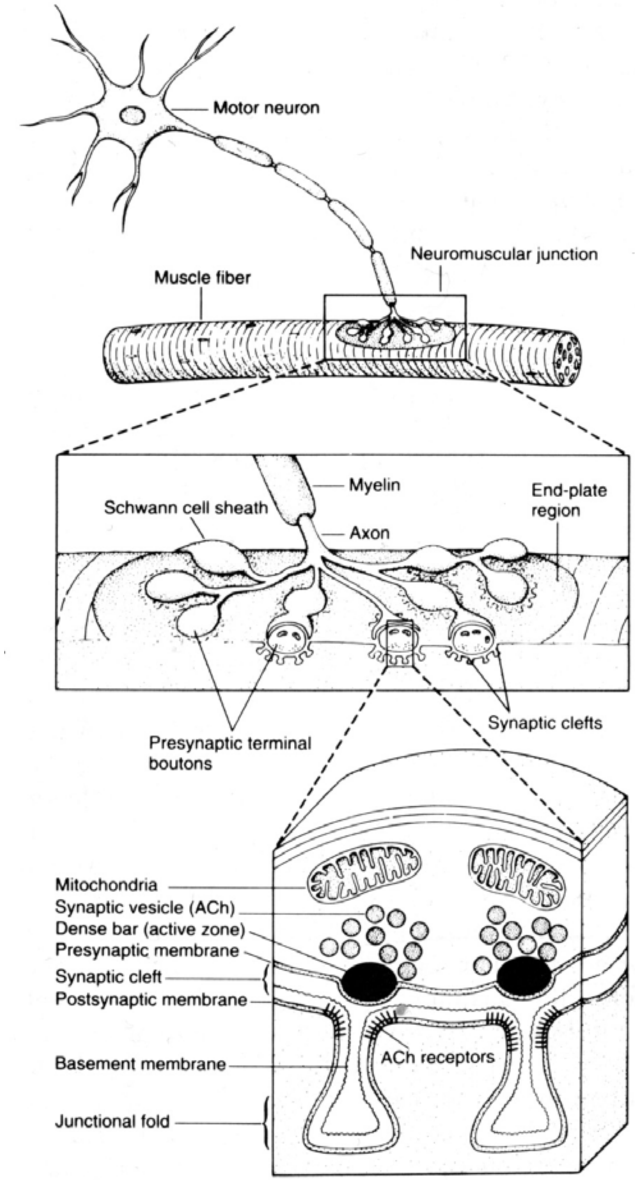
Szentagothai

THE PERIPHERAL (lower) MOTOR NEURON, THE MOTOR END-PLATE

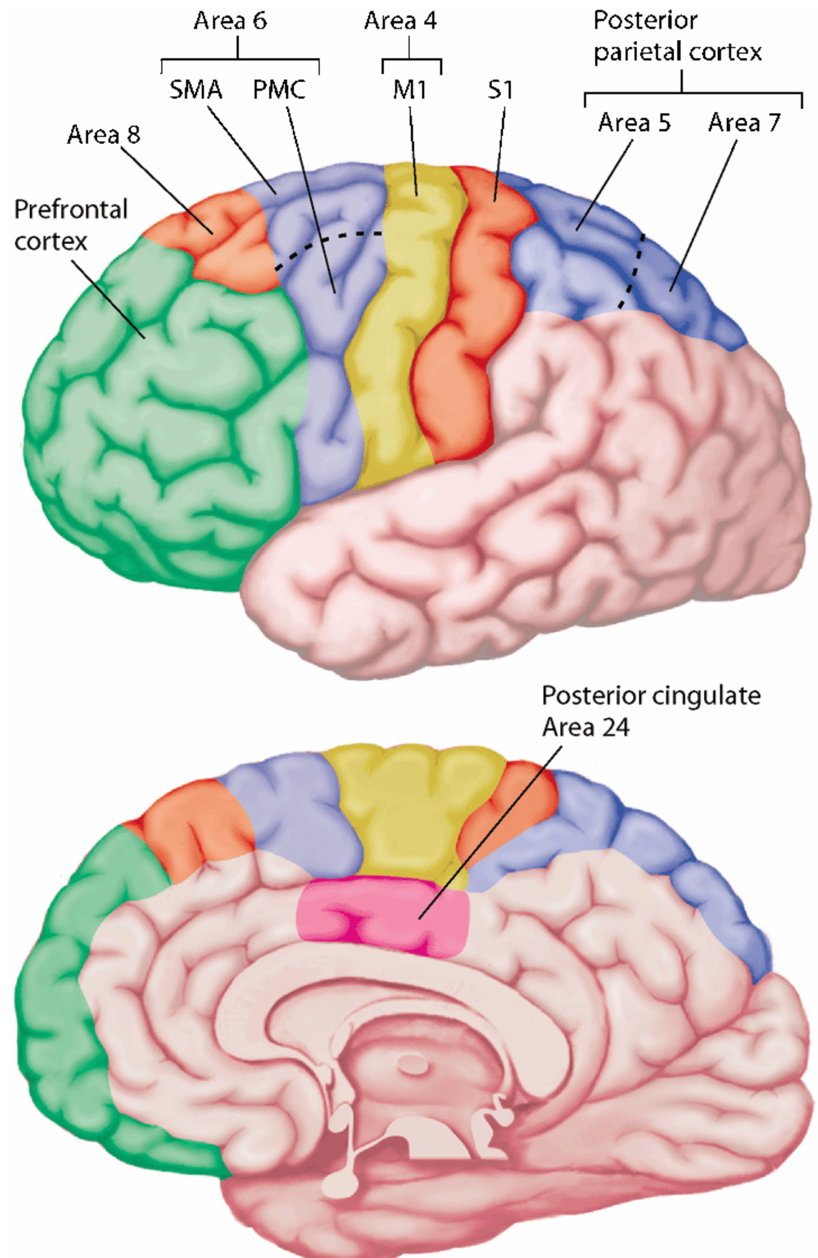




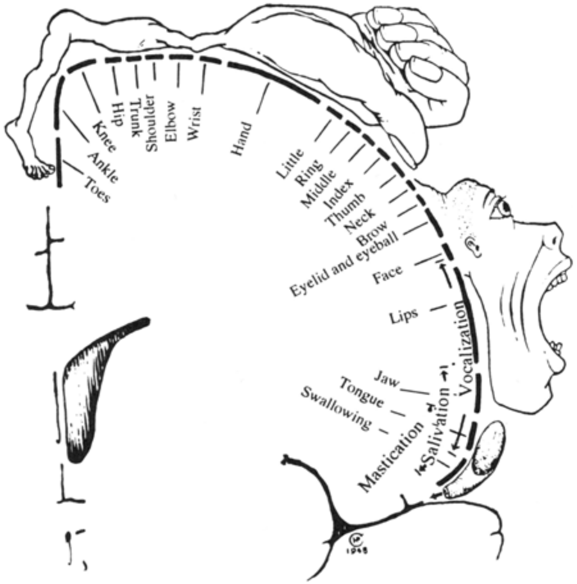


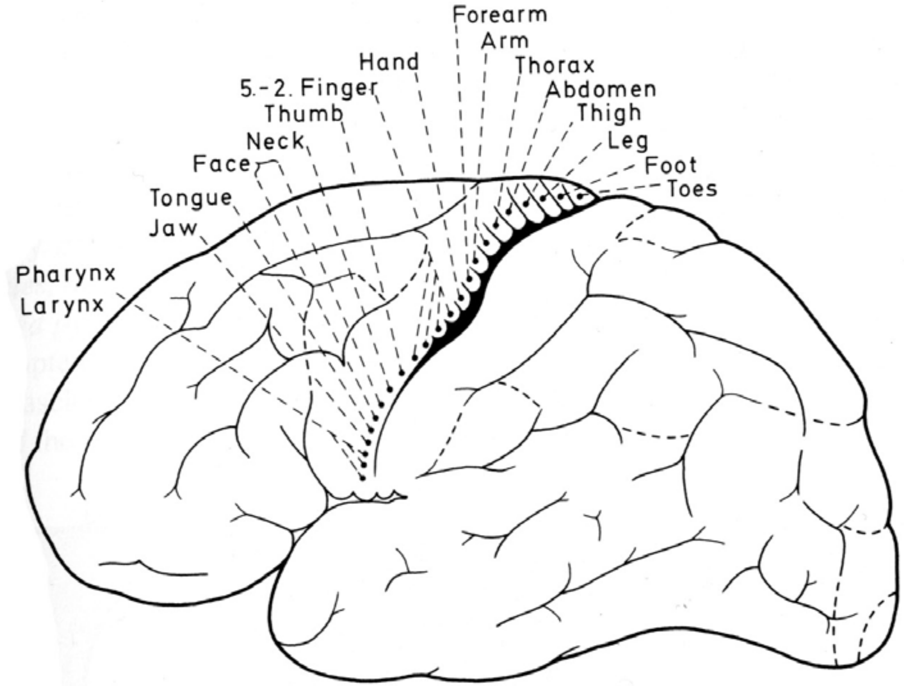


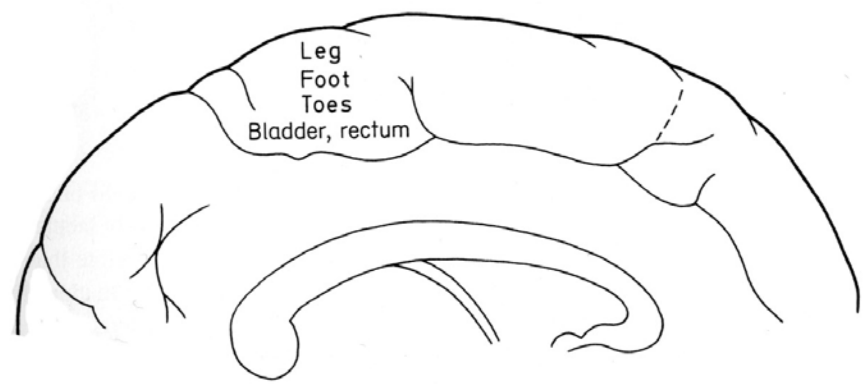
CORTICAL AREAS RELATED TO MOTOR CONTROL



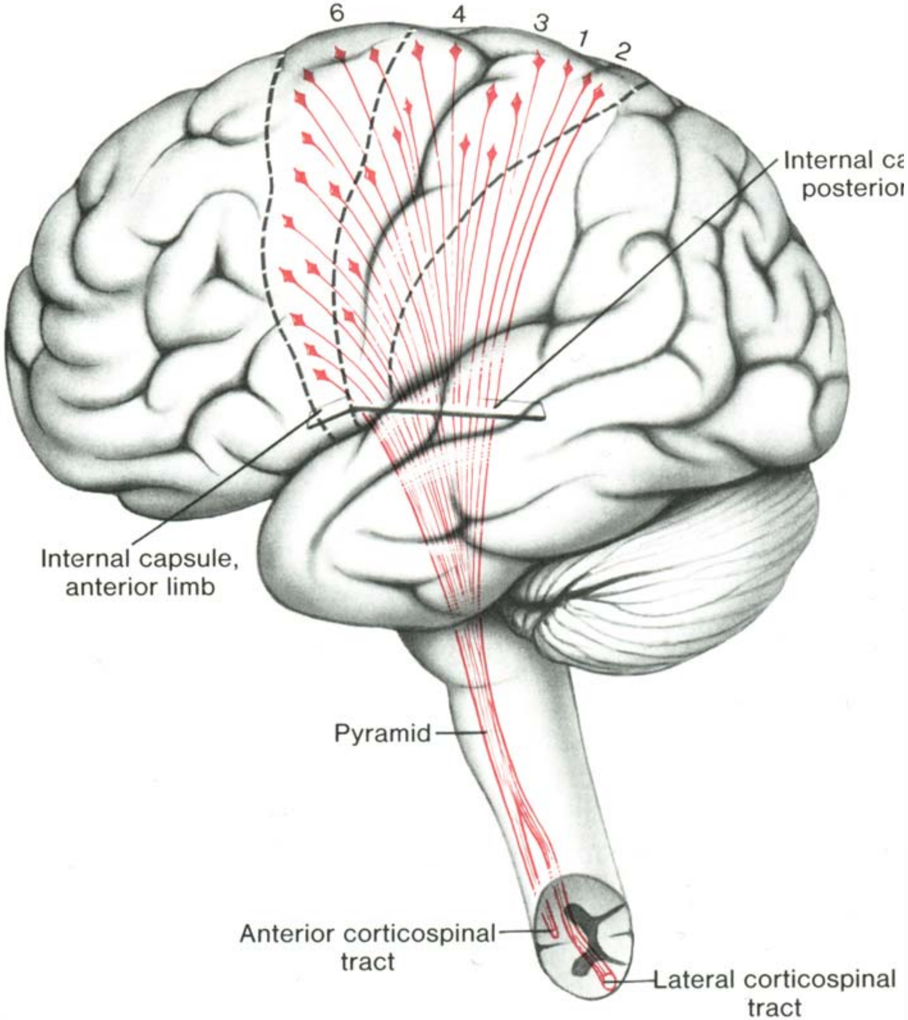
PRIMARY MOTOR CORTEX

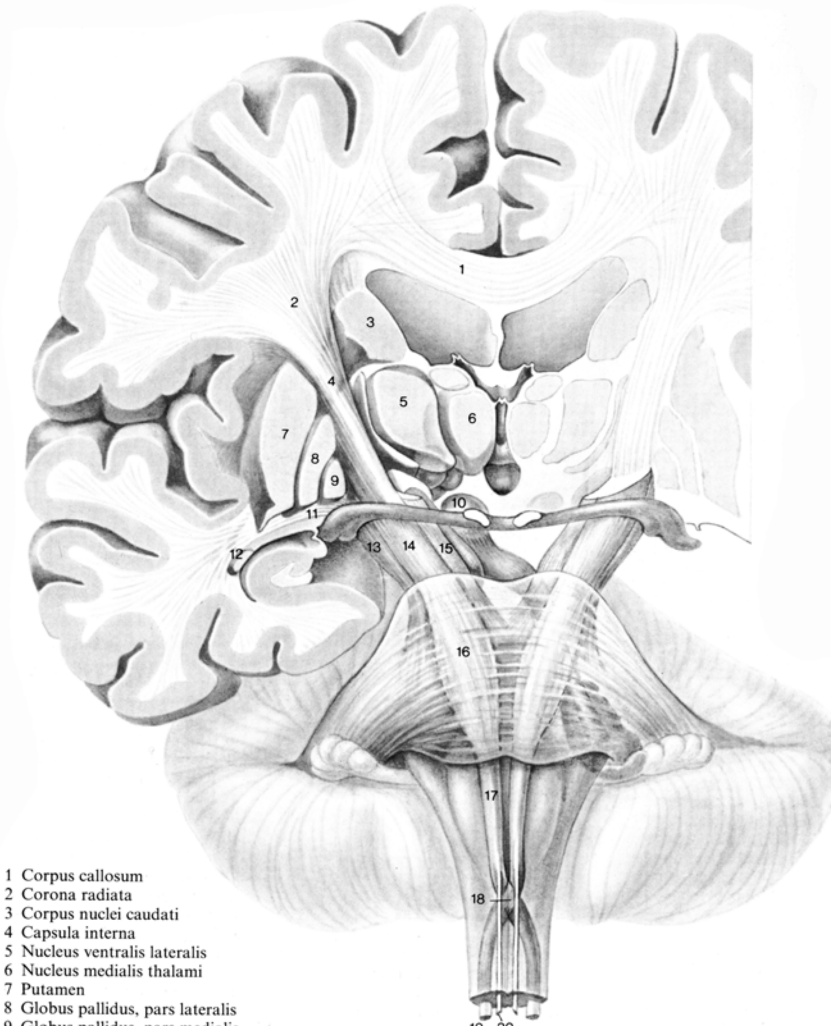






THE PYRAMIDAL TRACT 1.



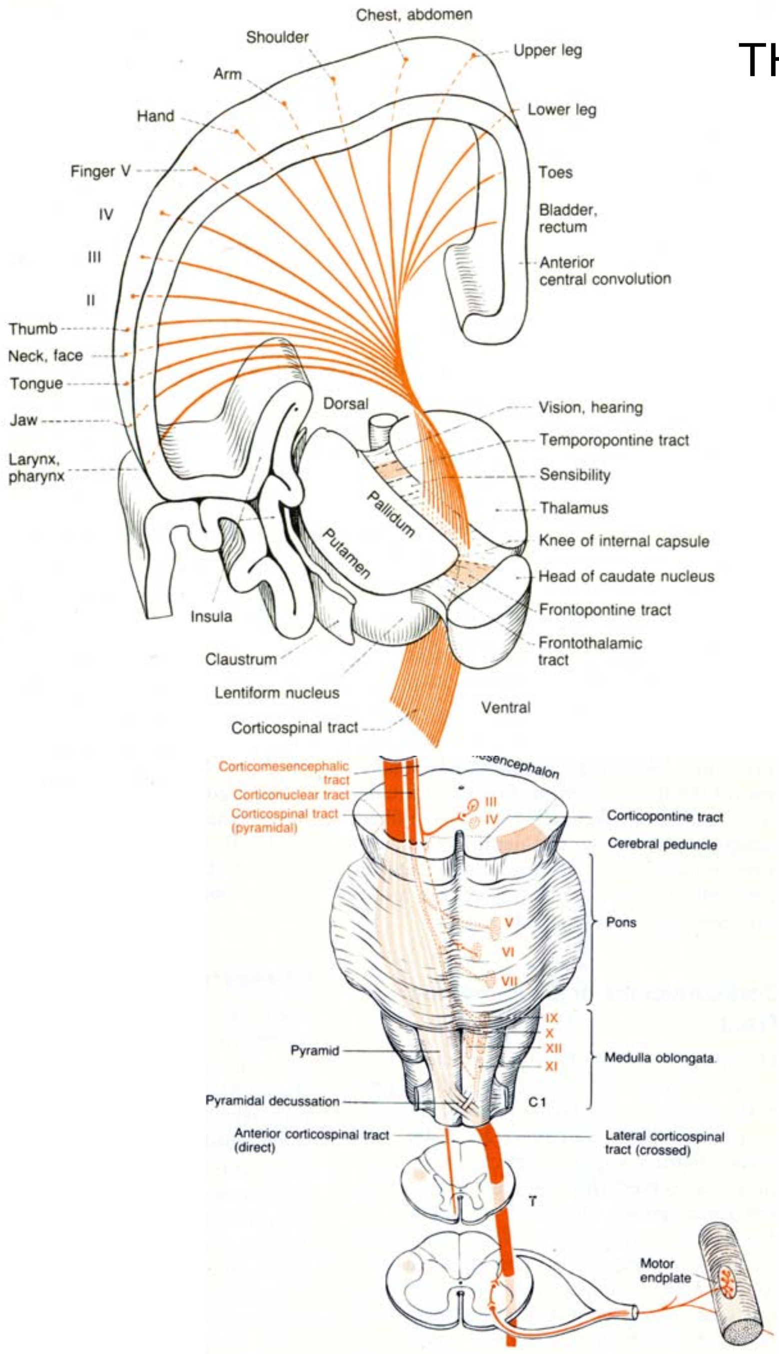


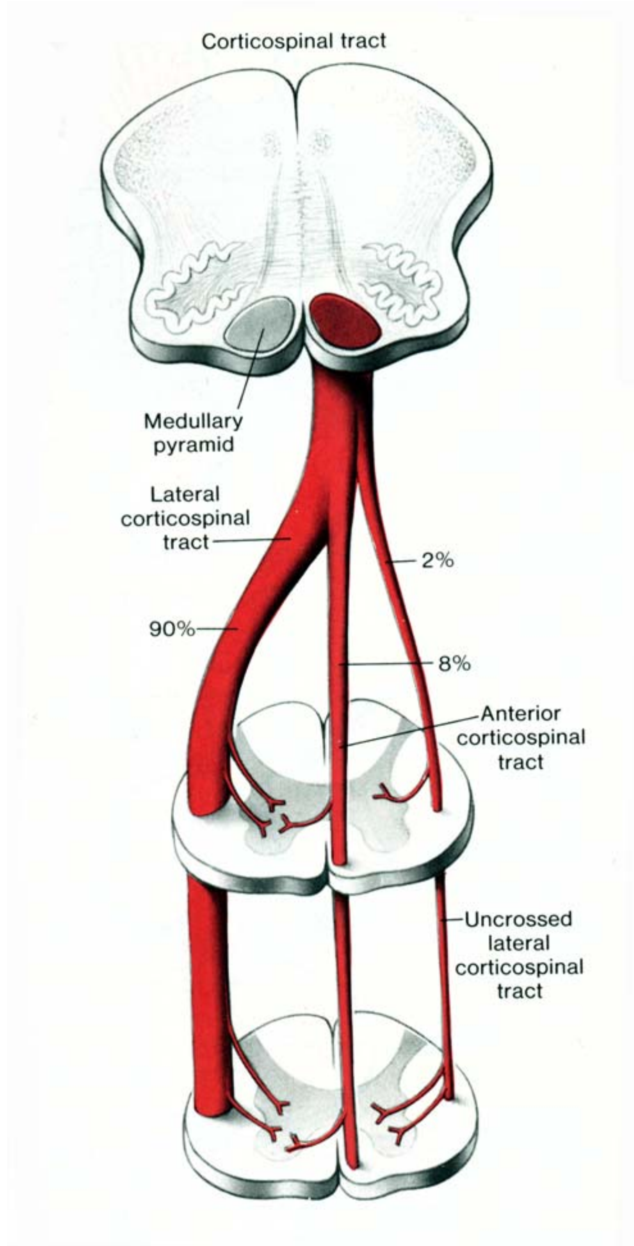
1 Corpus callosum
2 Corona radiata
3 Corpus nuclei caudati
4 Capsula interna
5 Nucleus ventralis lateralis
6 Nucleus medialis thalami
7 Putamen
8 Globus pallidus, pars lateralis
9 Globus pallidus, pars medialis
10 Nucleus ruber
11 Capsula interna, pars retrolentiformis
12 Cauda nuclei caudati
13 Tractus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

Pedunculus cerebri (13–15)

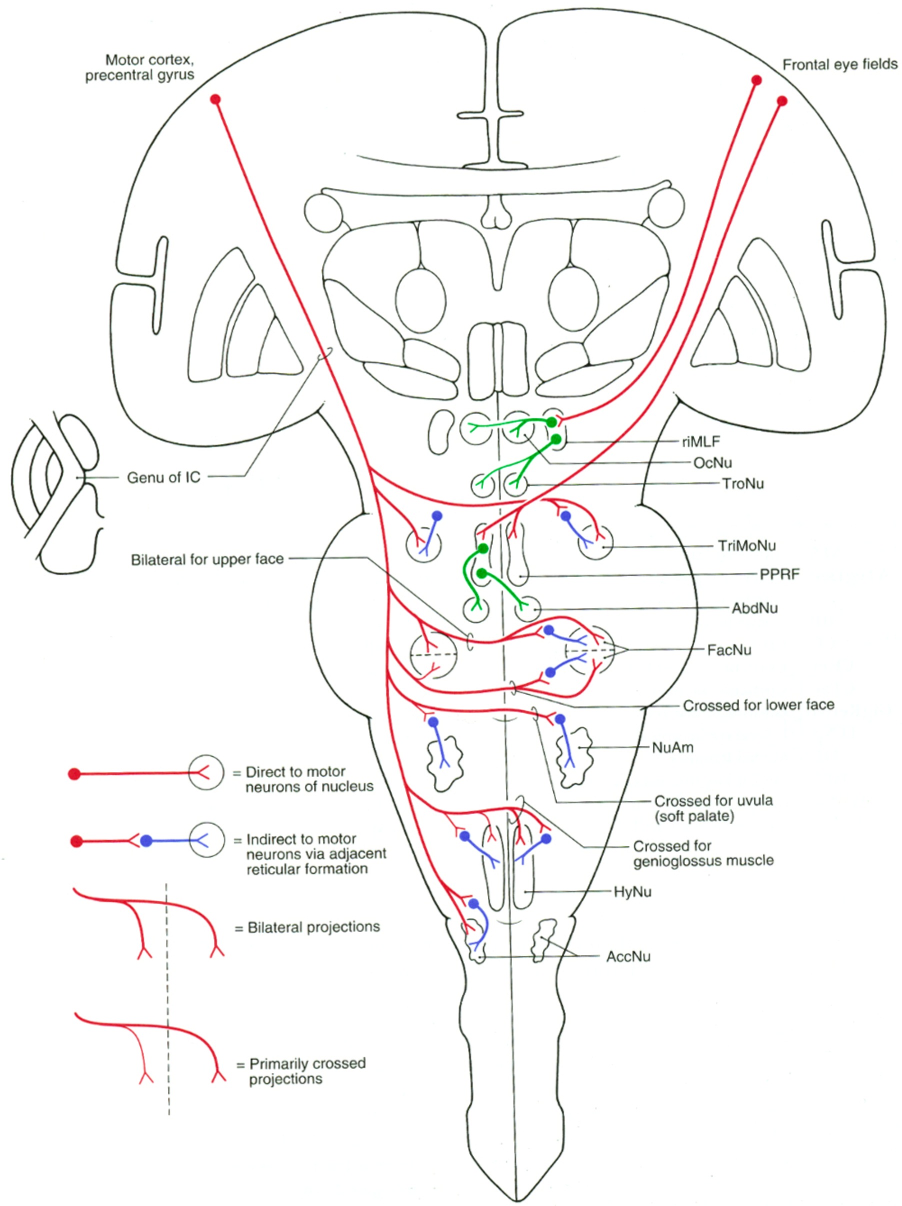
16 Pons
17 Pyramis
18 Decussatio pyramidum
19 Tractus pyramidalis lateralis
20 Tractus pyramidalis anterior

THE PYRAMIDAL TRACT 2.



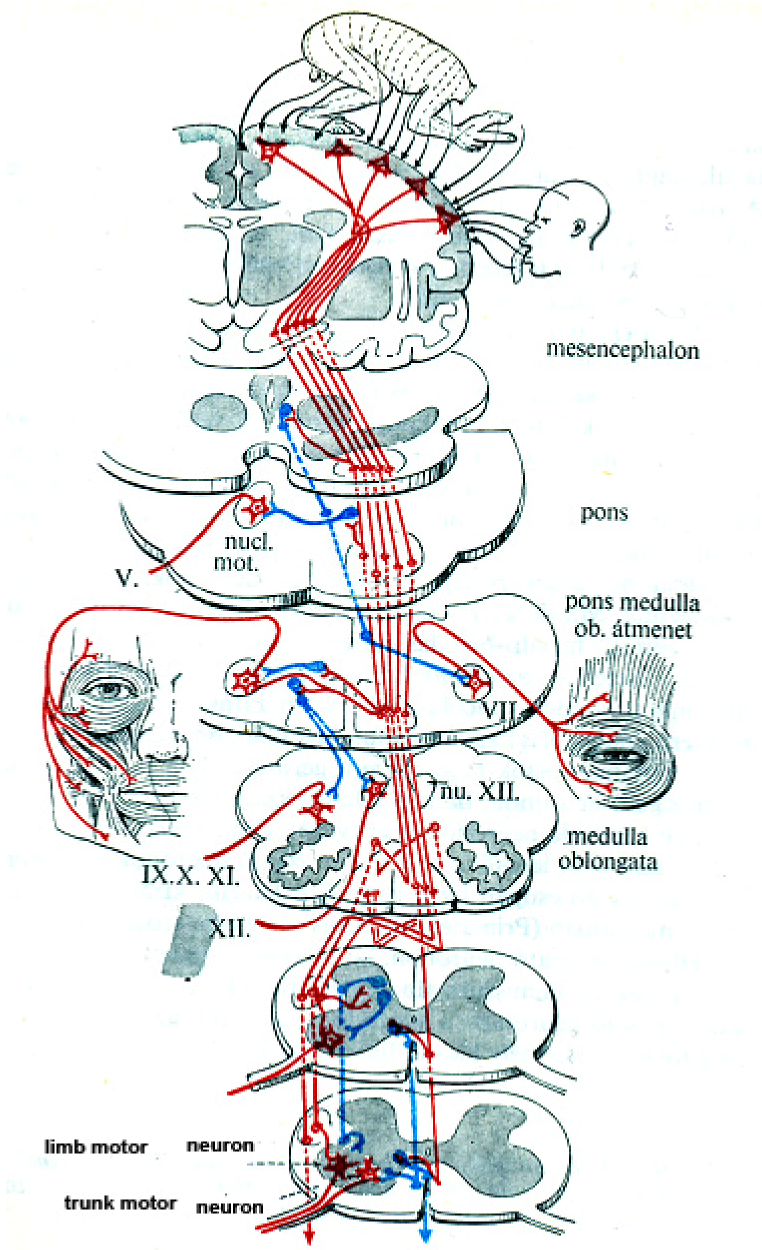


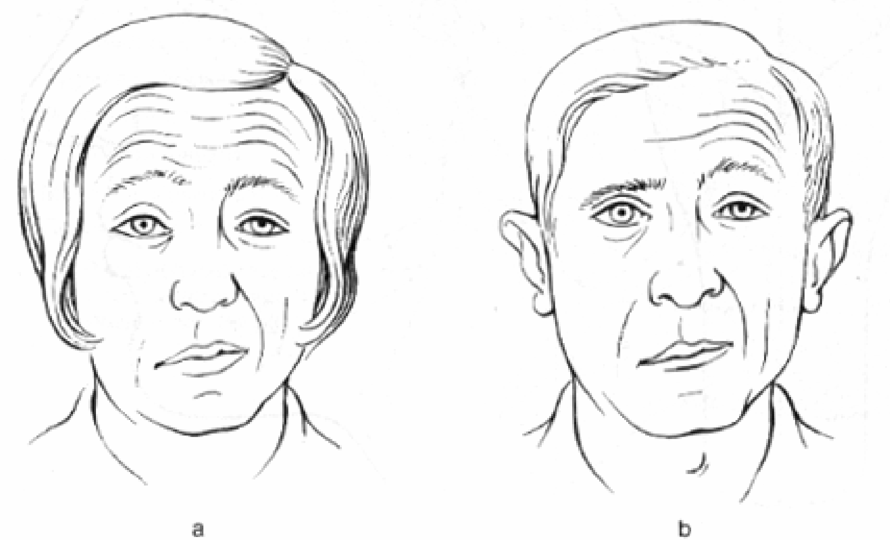
The corticobulbar tract (pyramidal tarct fibers to the cranial nerve motor nuclei)



Haines

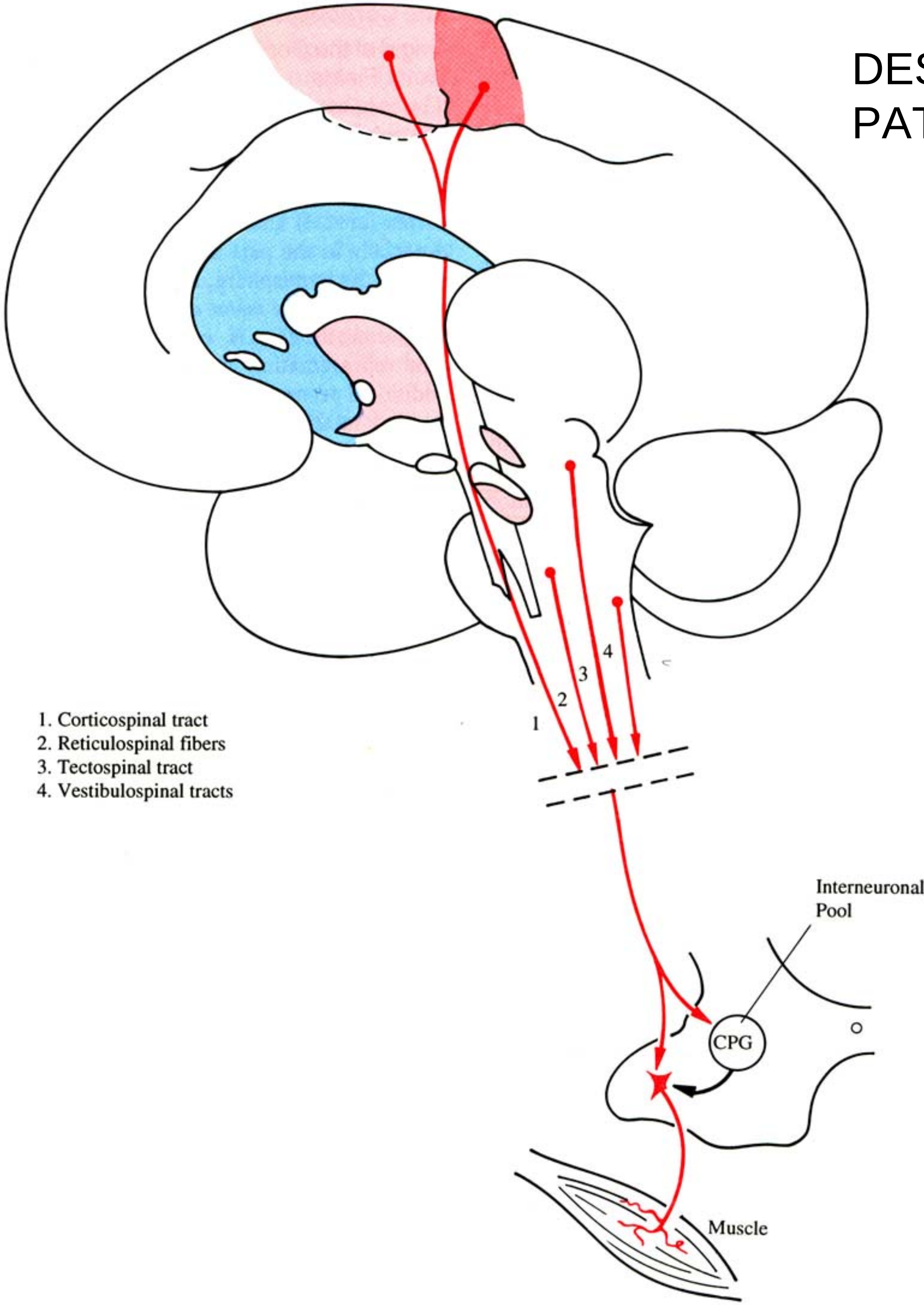
The Pyramidal system. Central and peripheral facial paresis.

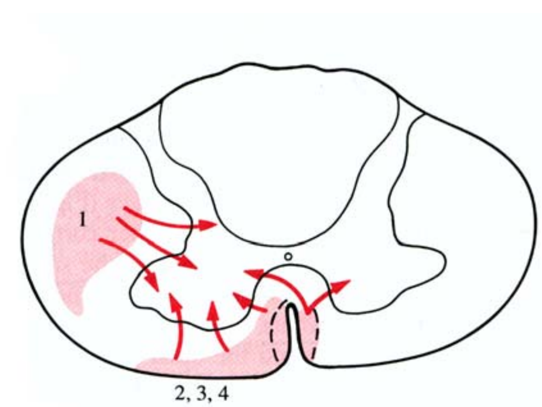




Central facial paralysis (left side) Peripheral facial paralysis (right side). The patient is asked to close her eyes and to retract their mouth

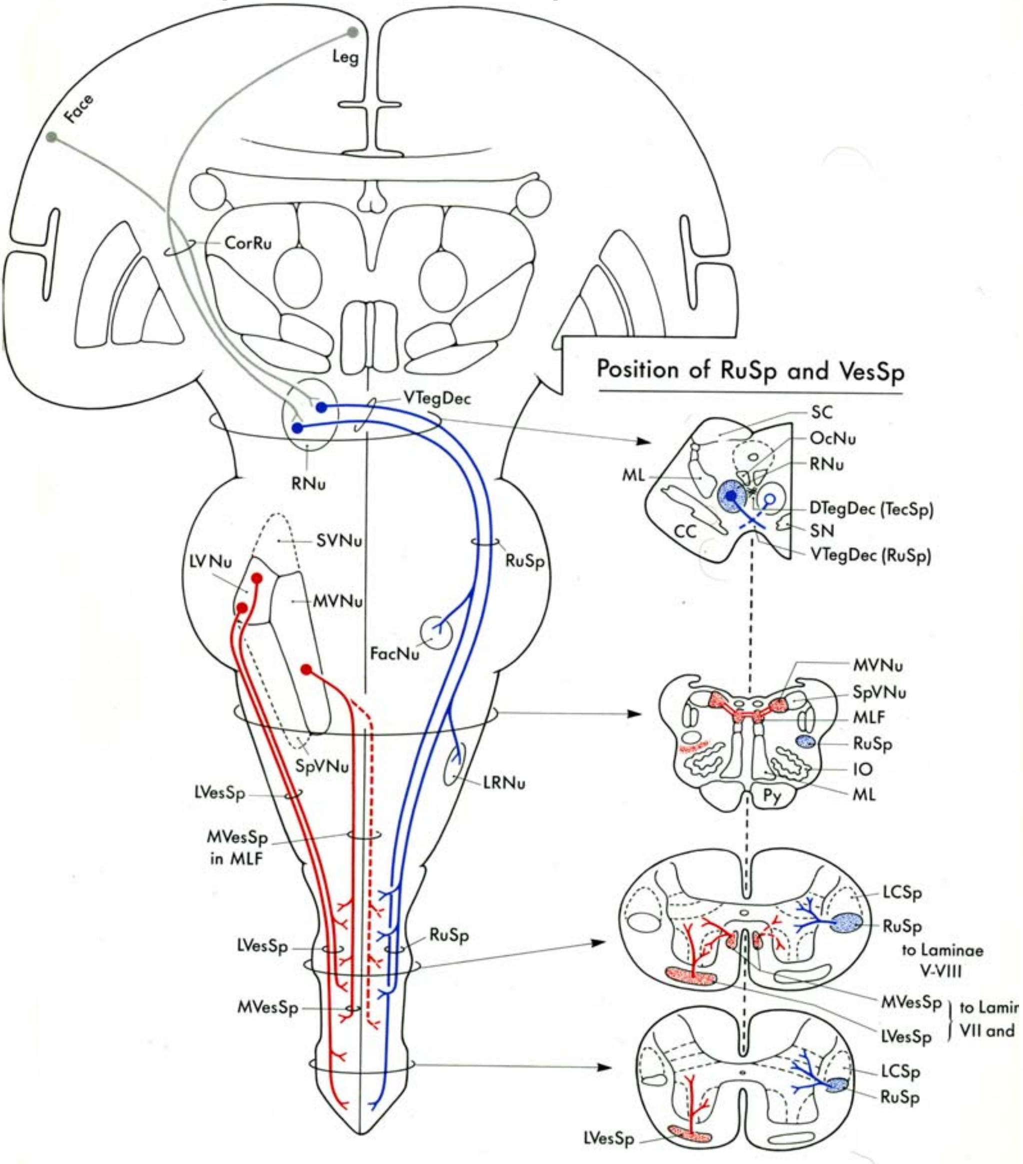
DESCENDING SUPRASPINAL PATHWAYS 1.



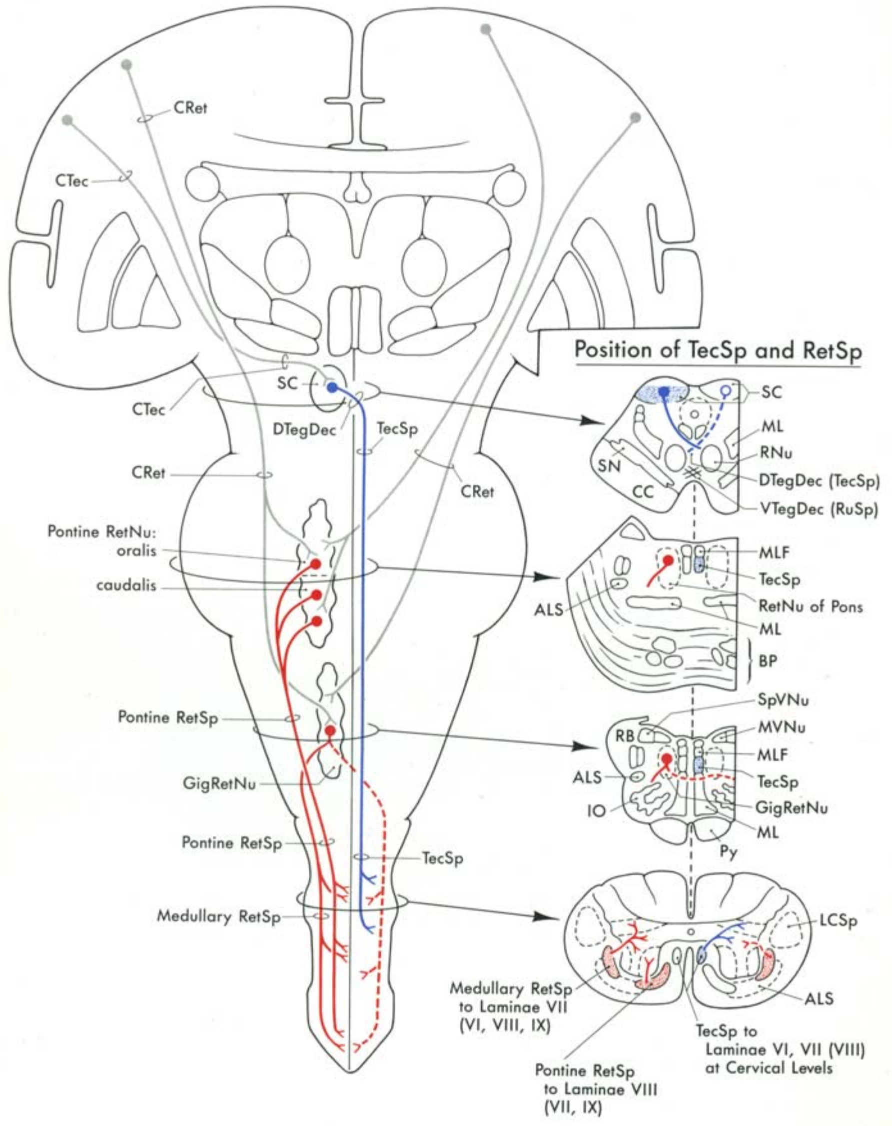


DESCENDING SUPRASPINAL PATHWAYS 2.

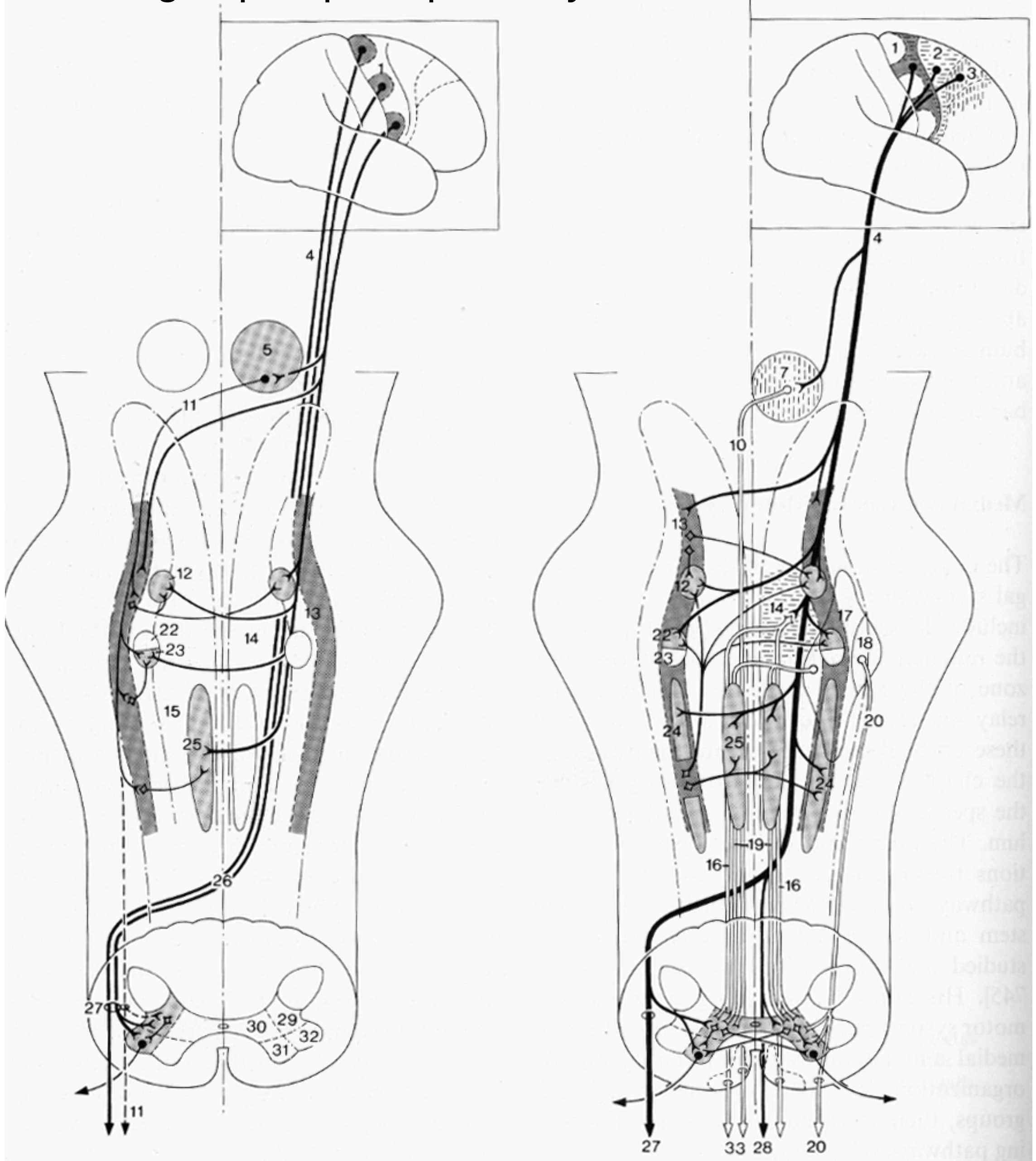
Rubrospinal-vestibulospinal



Tectospinal-reticulospinal pathways



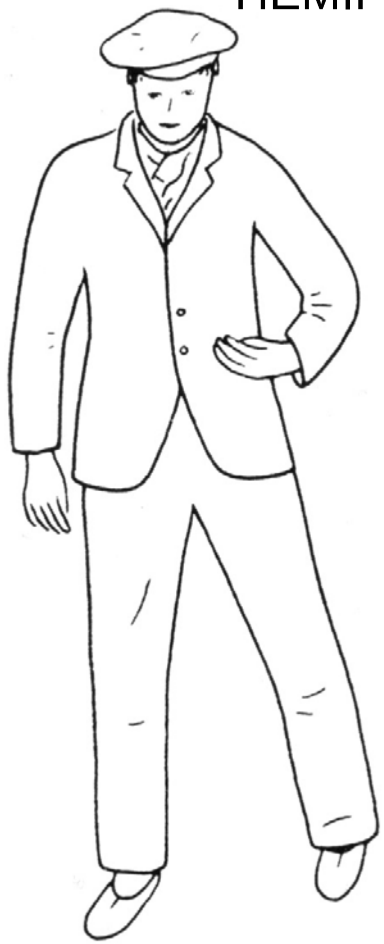
Descending supraspinal pathways 3.



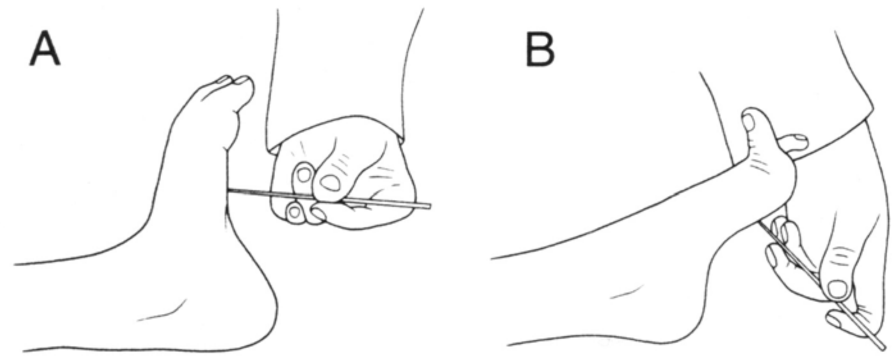
EXTRAPYRAMYDAL DESCENDING PATHWAYS

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 AND PATHOLOGICAL REFLEXES

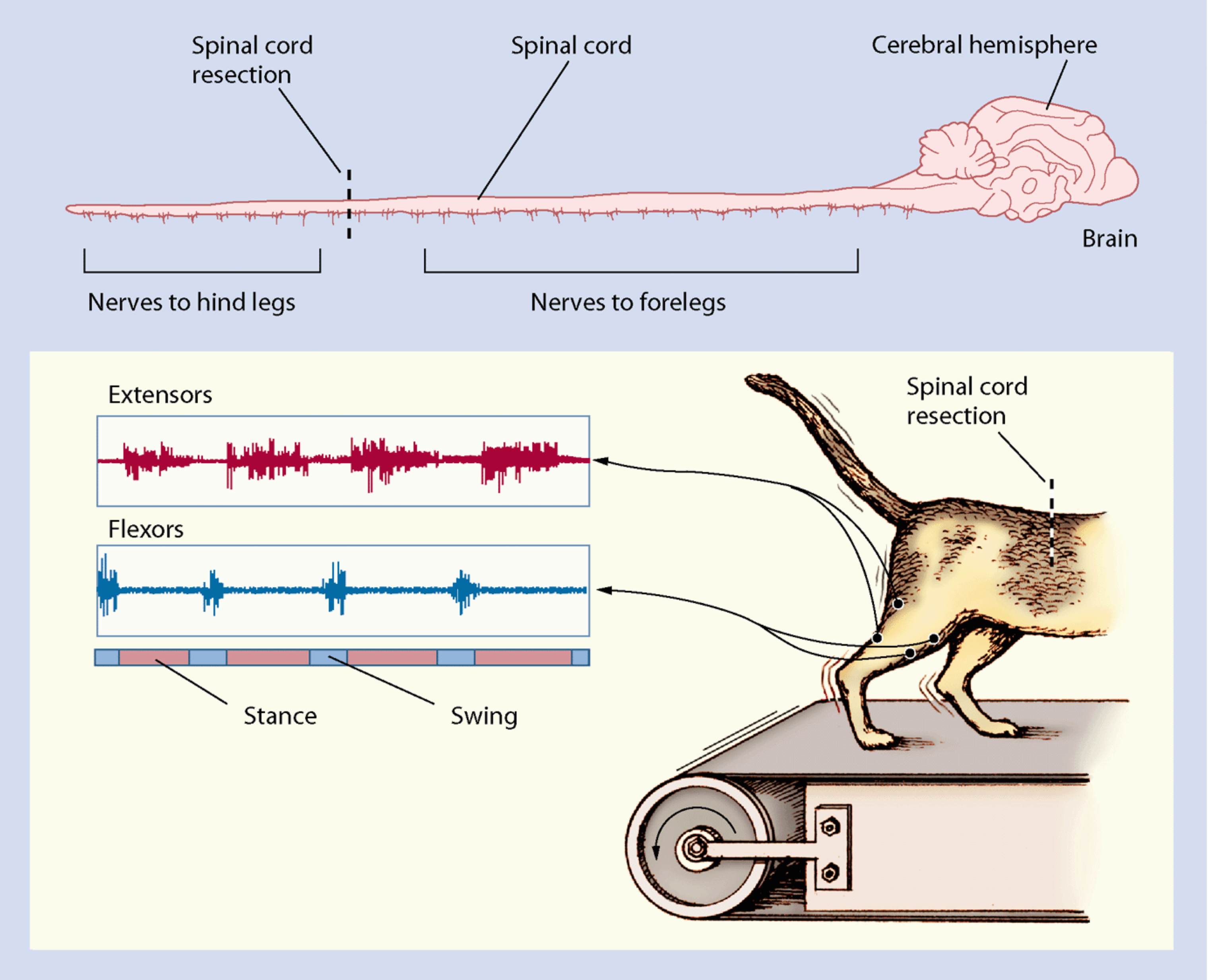


Hemiplegia of the left side. Note the characteristic position of the arm with flexion in the elbow and wrist. The paretic leg is moved laterally in a semicircle during the swing phase to keep the foot of the ground (circumduction) (From Brodal)

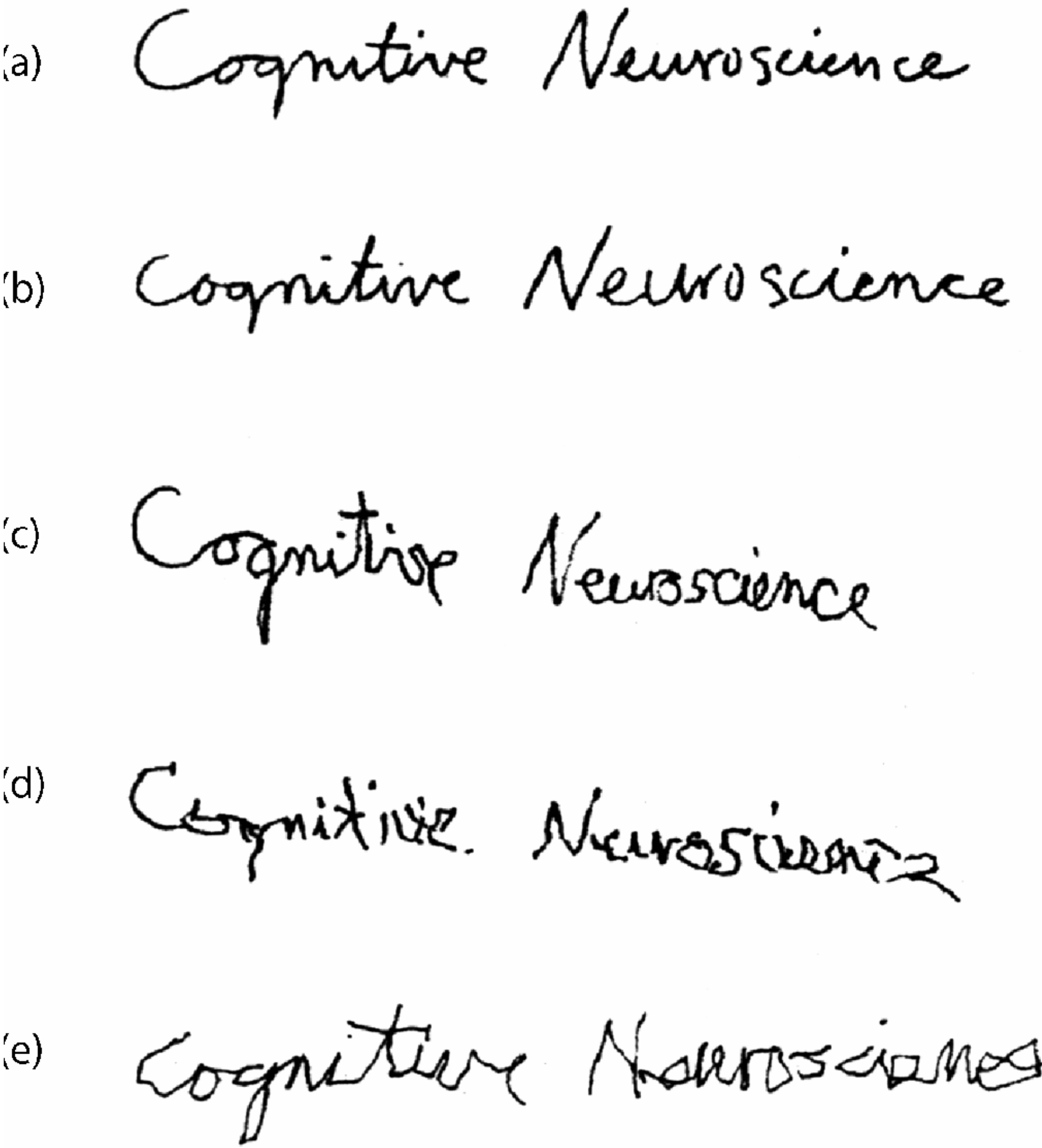


Inverted plantar reflex in central paresis (Babinski. A: normal. B: in a patient with damage of the pyramidal tract the big toe moves upward (dorsiflexion) (From Brodal)

CENTRAL PATTERN GENERATORS



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.



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)

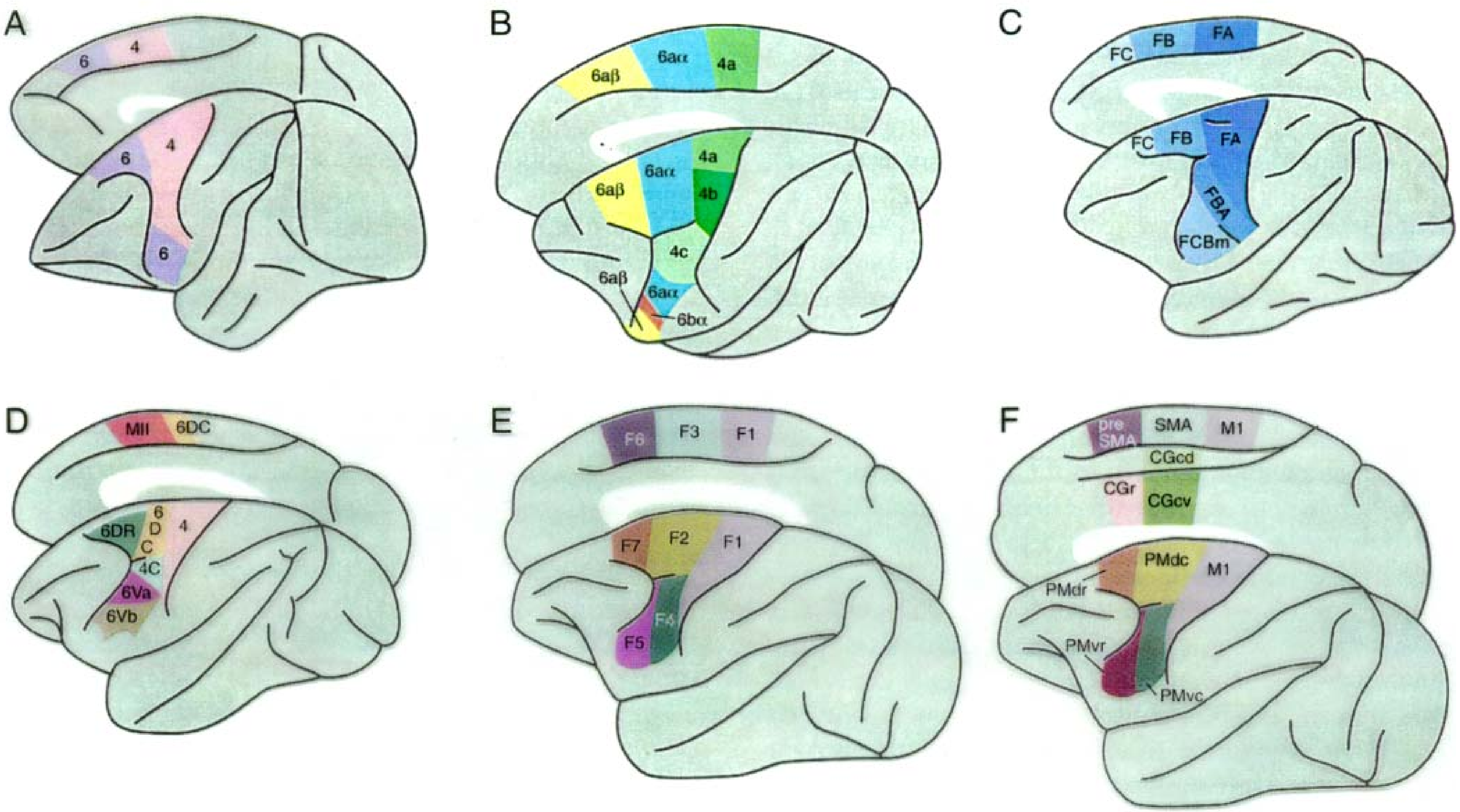
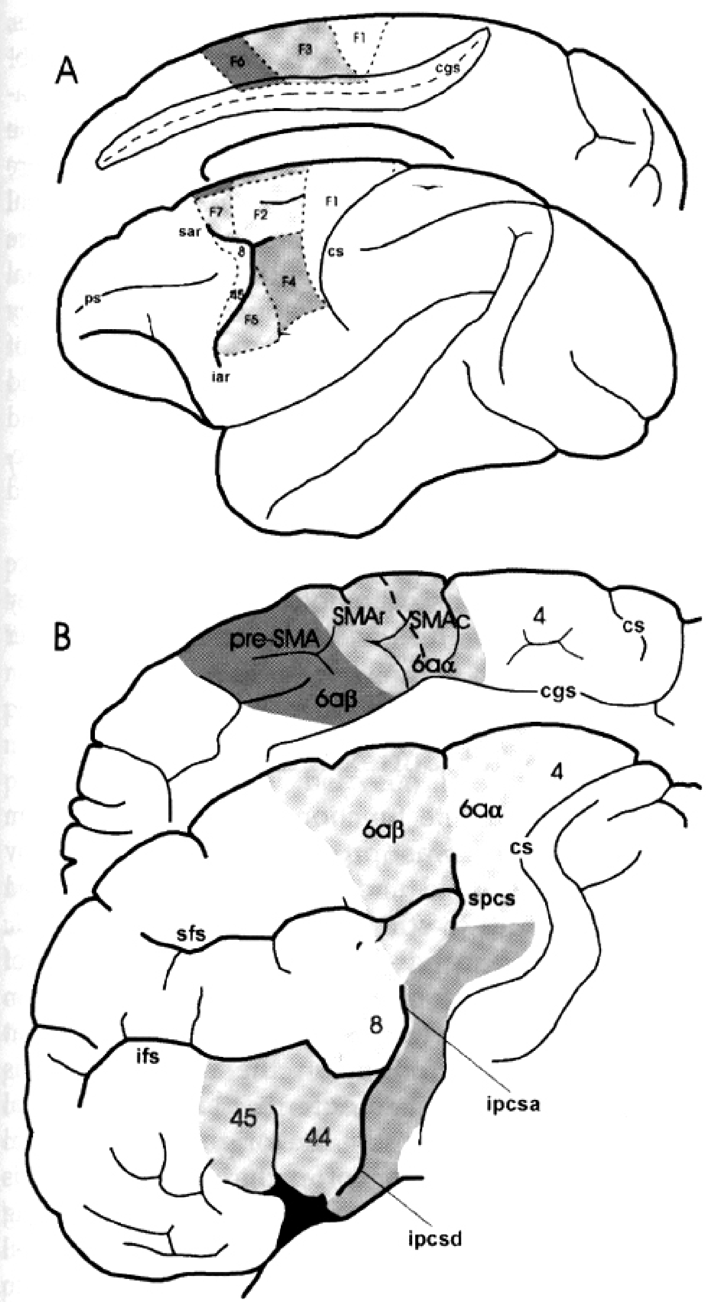
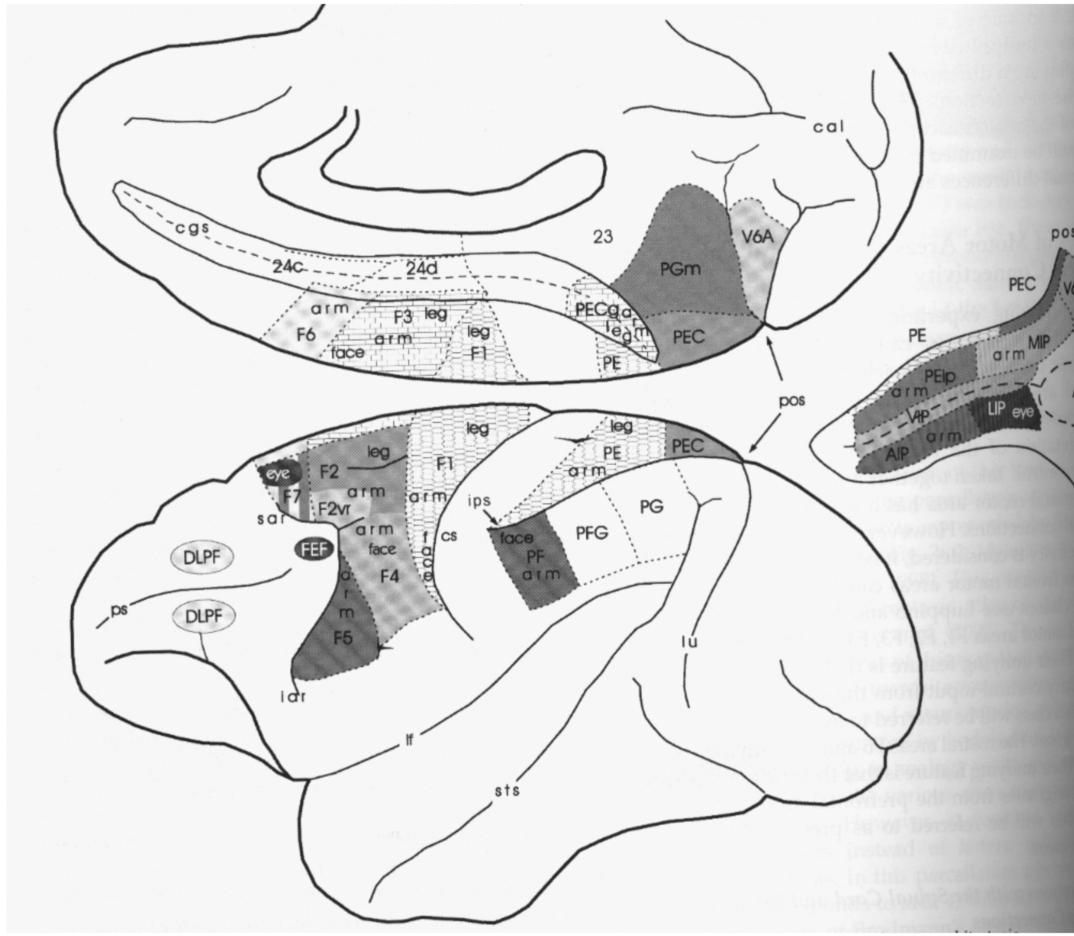


FIGURE 33.2 Cortical motor areas. Diagrams of a macaque brain show how the motor cortex of the frontal lobe has been parceled in various cytoarchitectonic studies over the past century. Modified from Matelli *et al.*[9] (A) Brodmann, 1903; (B) Vogt and Vogt, 1919; (C) Von Bonin and Bailey, 1947; (D) Barbas and Pandya, 1987; (E) Matteli *et al.*, 1991; (F) general abbreviations.


A
F6
F3
F1
cgs
F7
F2
F1
sar
8
cs
F4
ps
45
F5
iar
B
pre-SMA
SMAr
SMAc
6aα
6aβ
4
cs
cgs
4
6aβ
6aα
cs
spcs
sfs
8
ifs
ipcsa
45
44
ipcsd


cal
cgs
23
V6A
PGm
24c
24d
arm
F3
leg
F6
arm
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face
F1
PECg
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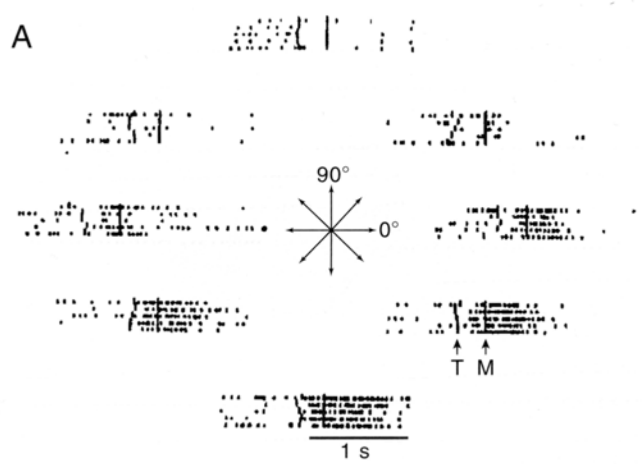
PE
pos
PEC
V6A
PE
MIP
arm
PEip
AG
VIP
LIP eye
arm
AIP
lu
leg
F2
eye
F1
leg
PE
PEC
F7
arm
ips
sar
F2vr
face
PF
arm
PFG
PG
FEF
cs
DLPF
F4
DLPF
ps
F5
lu
iar
lf
sts

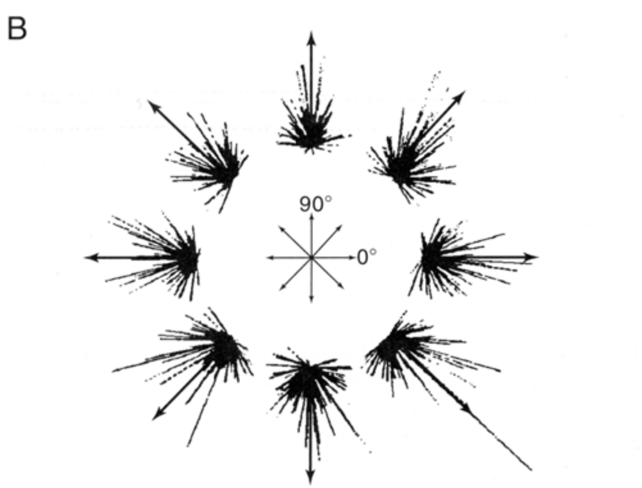
TABLE 33.1 Cortical Motor Areas and Cytoarchitectonics

<table>
<tr><th>Generic description</th><th>Generic abbreviation</th><th>Matelli et al.[9]</th><th>Barbas and Pandya</th><th>von Bonin and Bailey</th><th>Vogt and Vogt</th><th>Brodmann</th></tr>
<tr><td>Primary motor cortex</td><td>M1</td><td>F1</td><td>4</td><td>FA</td><td>4a, 4b, 4c</td><td>4</td></tr>
<tr><td>Premotor cortex, dorsal caudal</td><td>PMdc</td><td>F2</td><td rowspan="2">6DC</td><td rowspan="2">FB</td><td rowspan="3">6aα</td><td rowspan="6">6</td></tr>
<tr><td>Supplementary motor area-proper</td><td>SMA</td><td>F3</td></tr>
<tr><td>Premotor cortex, ventral, caudal</td><td>PMvc</td><td>F4</td><td>6Va</td><td>FBA</td></tr>
<tr><td>Premotor cortex, ventral, rostral</td><td>PMvr</td><td>F5</td><td>6Vb</td><td>FCBm</td><td>6bα,β</td></tr>
<tr><td>Pre-SMA</td><td>Pre-SMA</td><td>F6</td><td>MII</td><td rowspan="2">FC</td><td rowspan="2">6aβ</td></tr>
<tr><td>Premotor cortex, dorsal, rostral</td><td>PMdr</td><td>F7</td><td>6DR</td></tr>
<tr><td>Cingulate motor area, caudal</td><td>CGc</td><td>24d</td><td colspan="3"></td><td>23</td></tr>
<tr><td>Cingulate motor area, rostral</td><td>CGr</td><td>24c</td><td colspan="3"></td><td>24</td></tr>
</table>

Cortex	**Input**	**Output**	**Function**
M1(Primary Motor)	VL,S1 (3,1,2), par 5,6, PM	Brainstem Basal ganglia Red nucleus Reticular Formation (RF) Pyramidal tract	Activation of muscles primarily in distal part of extremities, face. Activity predominates during movement execution
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; movement selection reflecting external stimulus information
Parietal 5,7		PM	Goal directed reaching movement, exploratory hand movement, learned movement

MOTOR CORTEX ACTIVITY IS CORRELATED WITH MOVEMENT DIRECTIONS

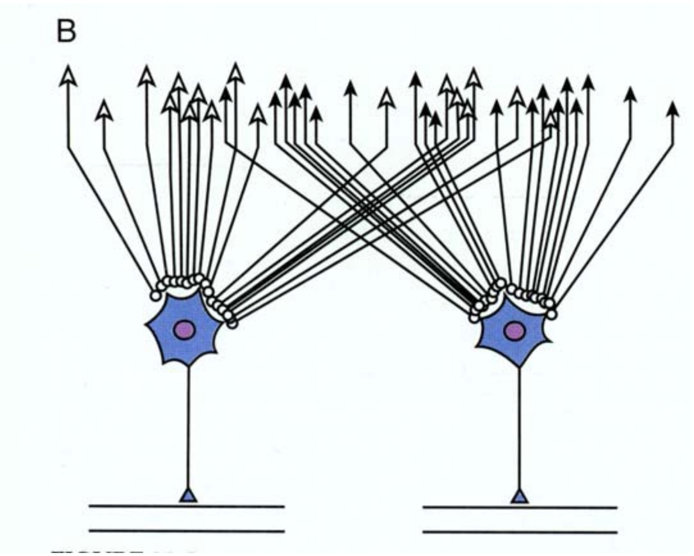




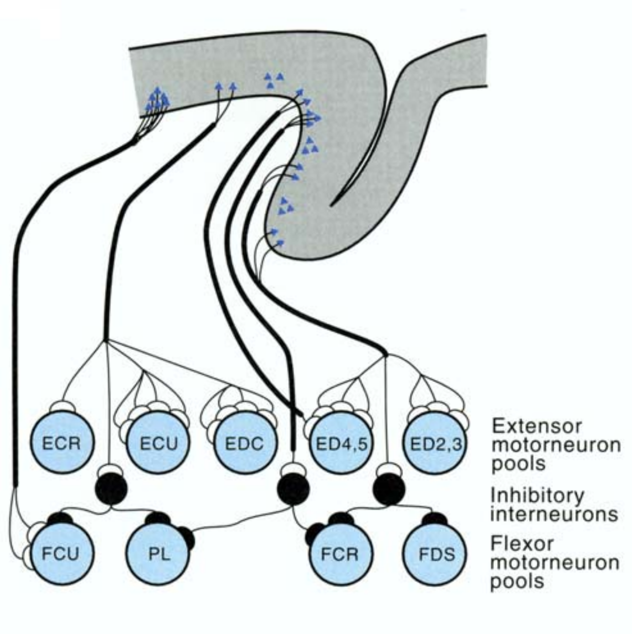
A The animal was trained to move a lever from the center location to one of 8 locations. The activity of motor cortex neuron is plotted next to each target location. Each row represent a single movement and the dots correspond to action potentials. The eight rasters show that this neuron's activity was 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 any 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)

INNERVATION PATTERN OF SINGLE M1 NEURONS

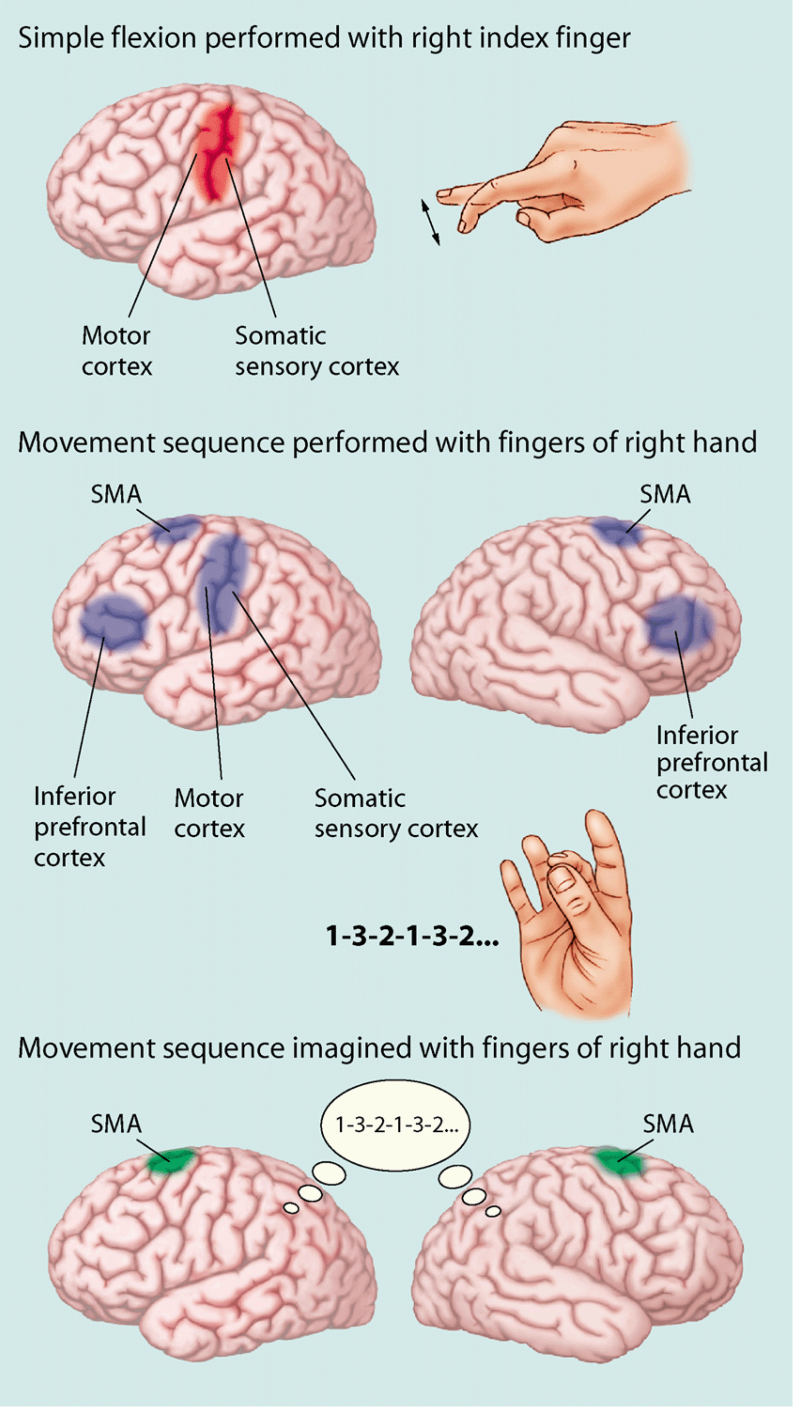
A



C



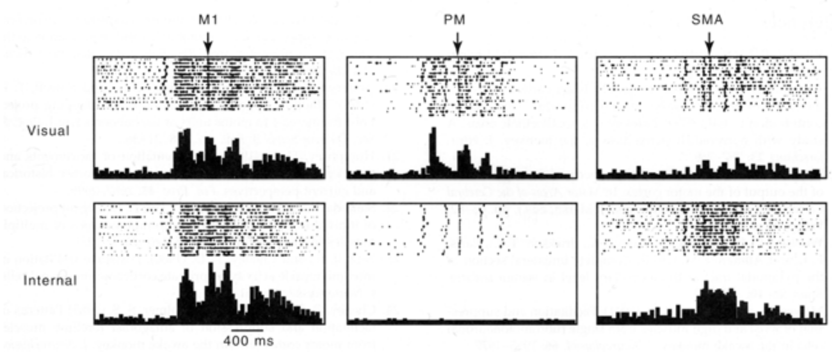
A: Divergence of M1outputs to multiple muscles. Tracing of a single corticospinal axon ramifying in the ventral horn of the spinal cord shows terminal fields in the motor neuron pools of four forearm muscles (Shinoda et al). C: Output of single corticospinal neurons often diverges to influence multiple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



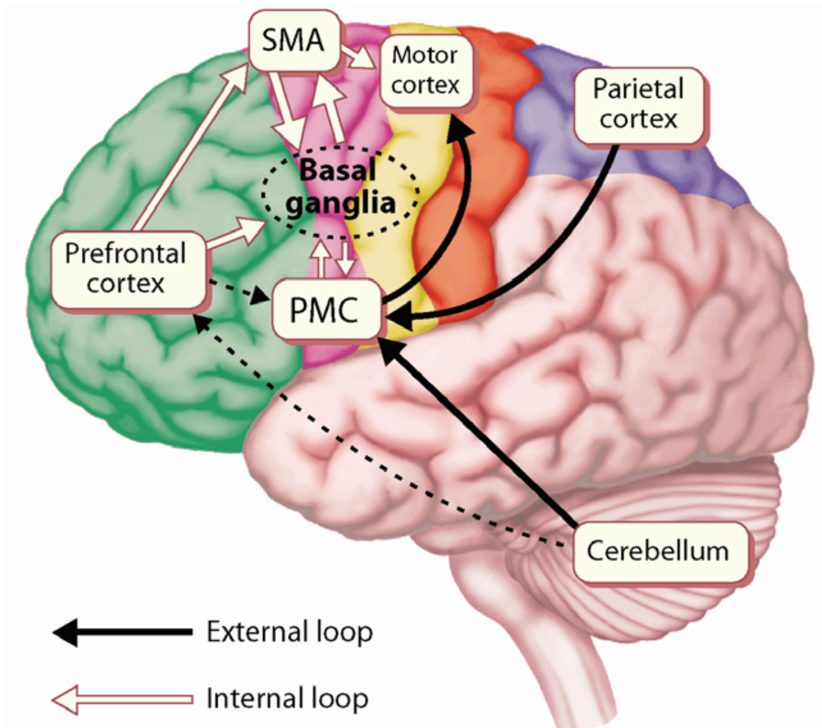
AREAS OF METABOLIC ACTIVITY IN VARIOUS MOTOR TASKS

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).

PLANNED MOVEMENTS FROM INTERNAL OR EXTERNAL STIMULI

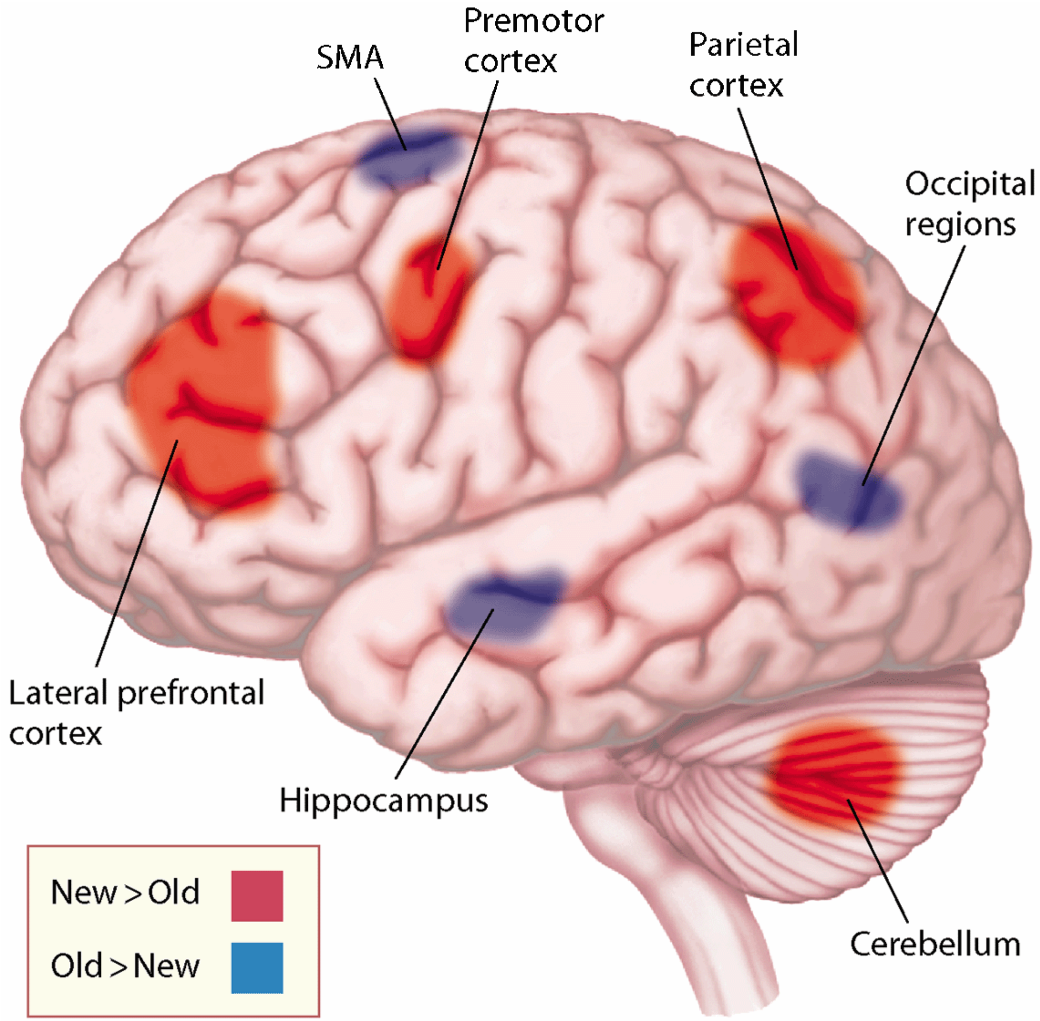


Activity of 3 neurons, - one in M1, one in PM and one in SMA- recorded as a monkey pressed 3 buttons in sequence. The sequence was first visually cued by lighting the buttons and then internally cued. The M1 neuron showed similar activity whether the monkey performed from visual or internal cues. The 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).



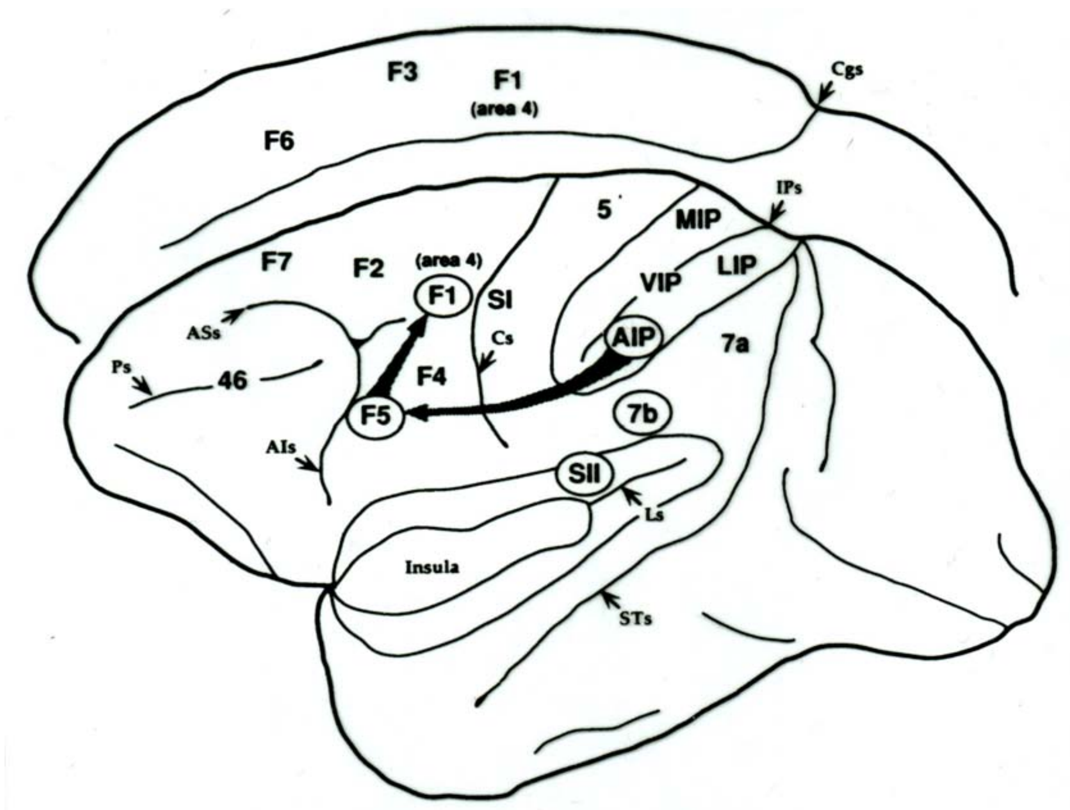
Movements may vary in terms of the contribution of internal and external sources of information. The external loop, including the cerebellum, parietal lobe, and lateral premotor cortex (PMC) dominates during visually guided movements. The internal loop, including the basal ganglia and SMA, dominate during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

SHIFT OF METABOLIC ACTIVITY DURING MOTOR LEARNING



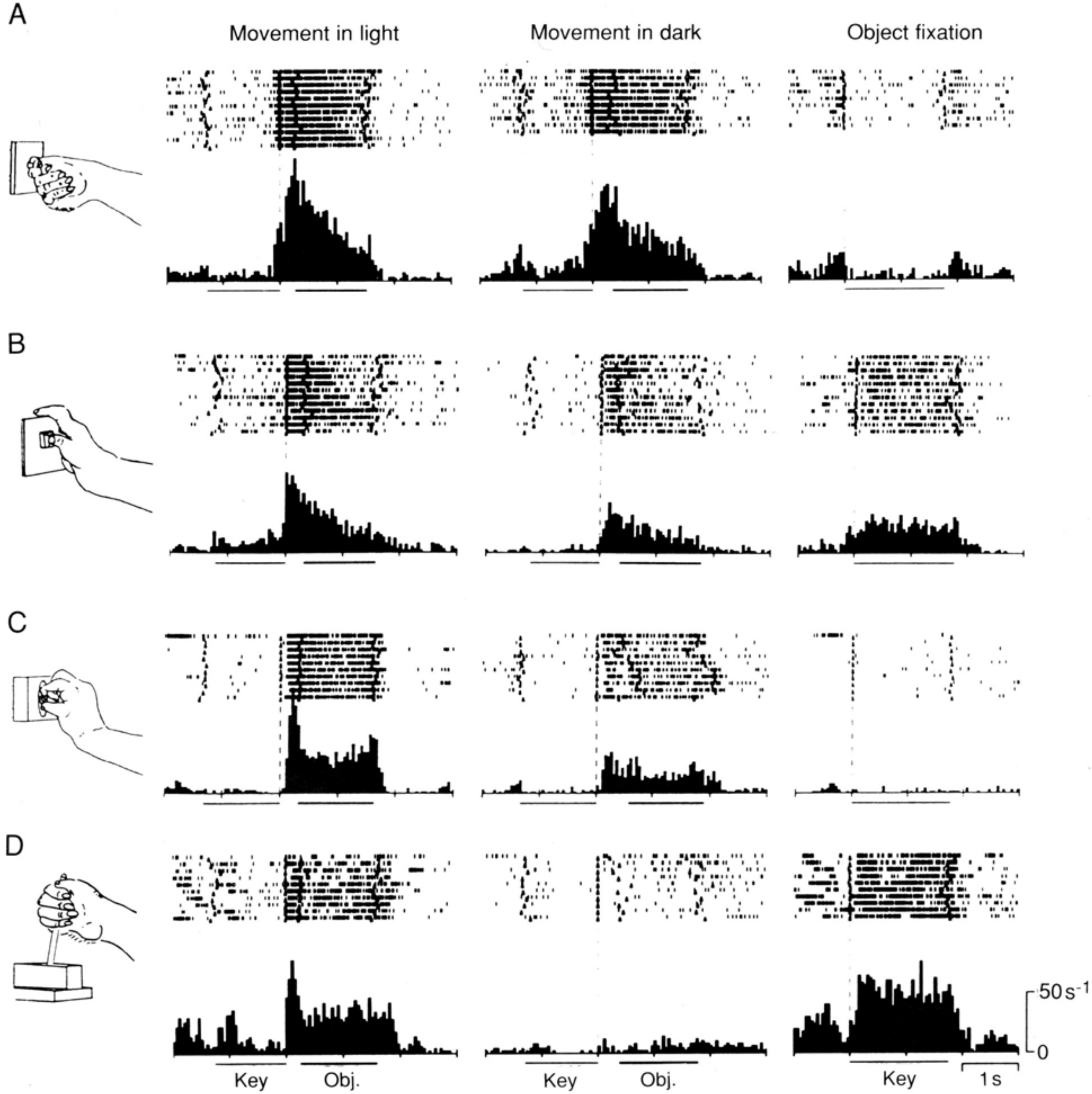
PET scans were obtained under two conditions: while subjects performed a well-learned movement sequence (Old) and during the course of learning of a movement sequence (New). Learning was associated with blood flow increases in lateral premotor and prefrontal areas; in contrast, performance of previously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

SENSORY-MOTOR INTEGRATION IN MONKEYS



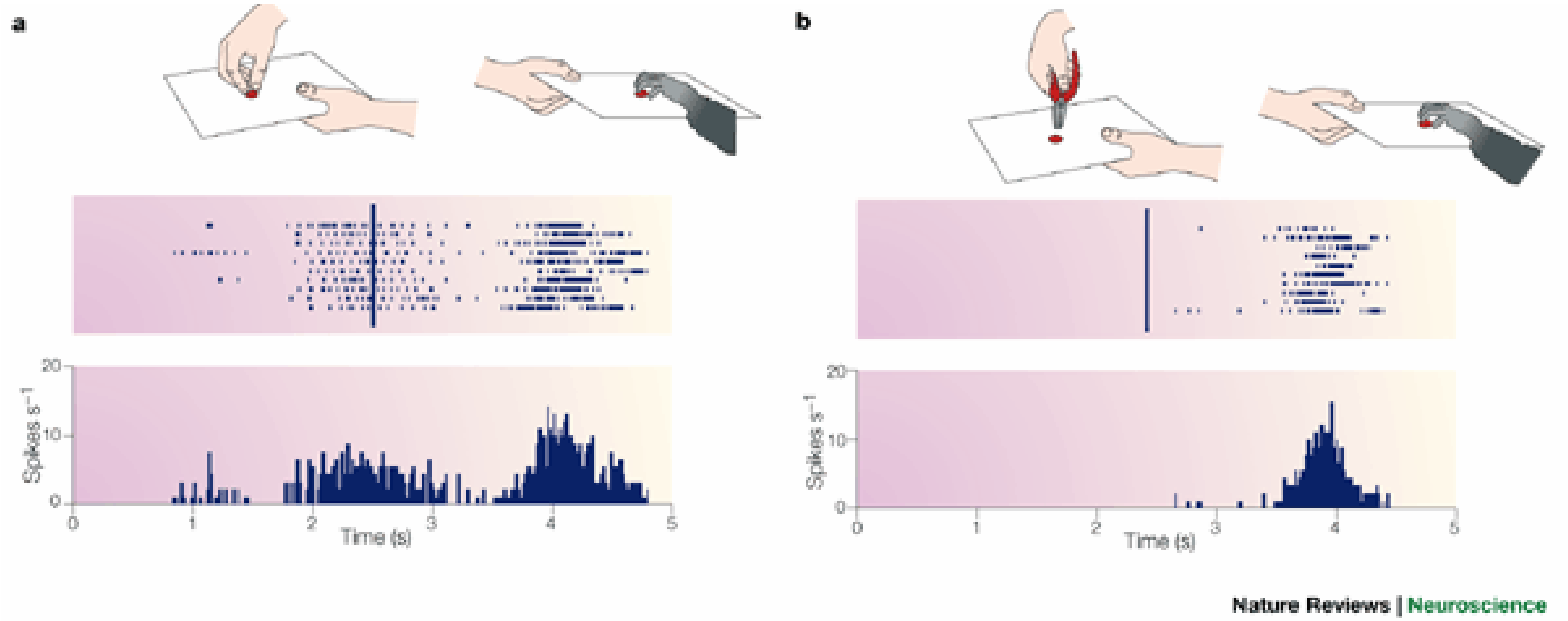
Lateral and medial views of the monkey cerebral cortex. The visuomotor stream for grasping is indicated by large arrows. F5 also receives somatosensory input from areas SII, and somatosensory and visual input from area 7b (circled areas). Cortical areas that control grasping are connected with basal 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)

NEURAL ACTIVITY IN INTRAPARIETAL AREA AIP DURING HAND MANIPULATION



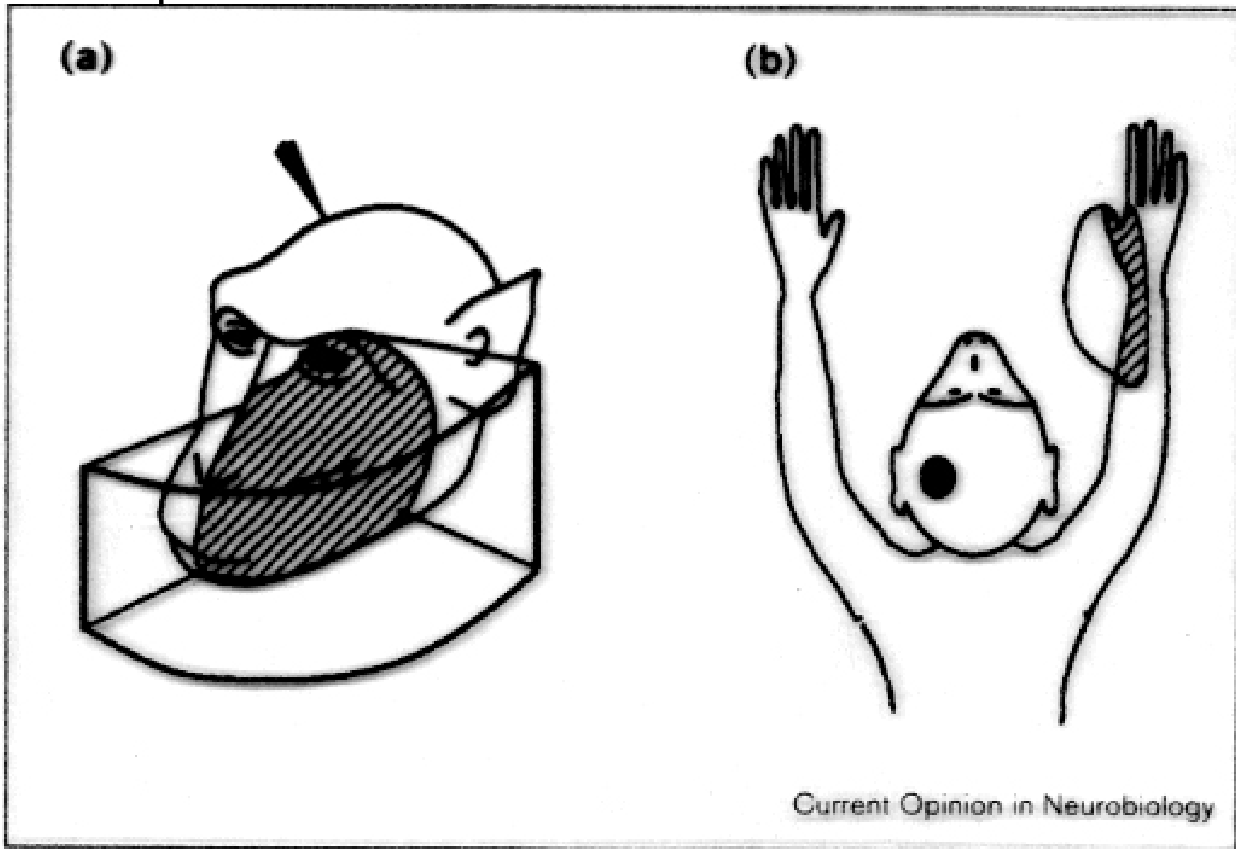
Activity of cells during hand manipulation in light and in dark, as well as during visual fixation objects, is shown with rasters and histograms. Key indicates the period of pressing the anchor key before moving to the object. Obj. indicates the period of holding the object to keep the switch on (Jeannerod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

MIRROR NEURONS IN AREA F5 (Premotor ventral)



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

Receptive fields in the Premotor cortex.



Receptive fields of two bimodal, visual–tactile neurons in PMv. **(a)** The tactile receptive field (striped) is on the snout, mostly contralateral to the recording electrode (indicated by the arrowhead) but extends partially onto the ipsilateral side of the face. The visual receptive field (boxed) is contralateral and confined to a region of space within about 10 cm of the tactile receptive field. **(b)** The tactile receptive field for this neuron is on the hand and forearm contralateral to the recording electrode (indicated by the black dot), and the visual receptive field (outlined) surrounds the tactile receptive field.

Grasping neurons in the premotor cortex (PMv)

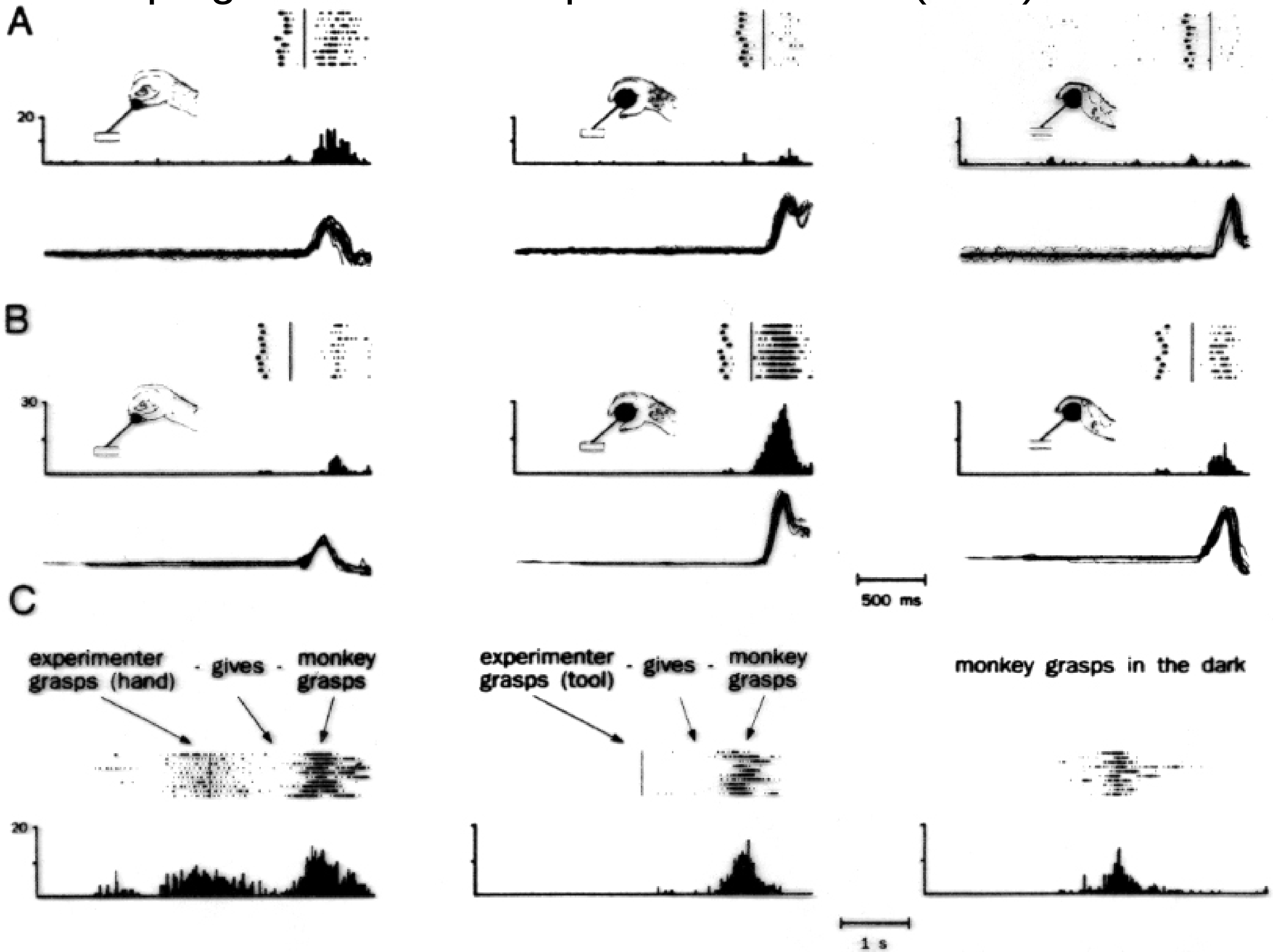
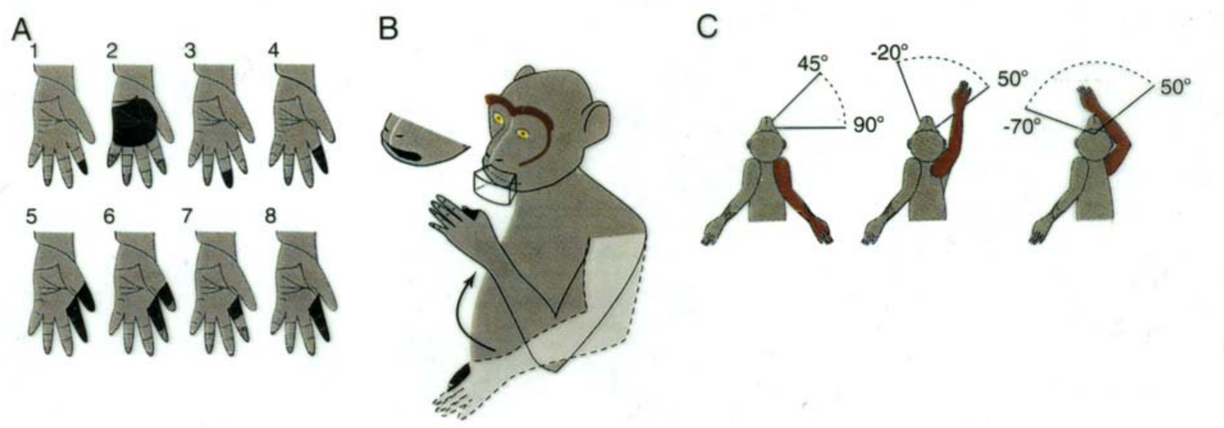


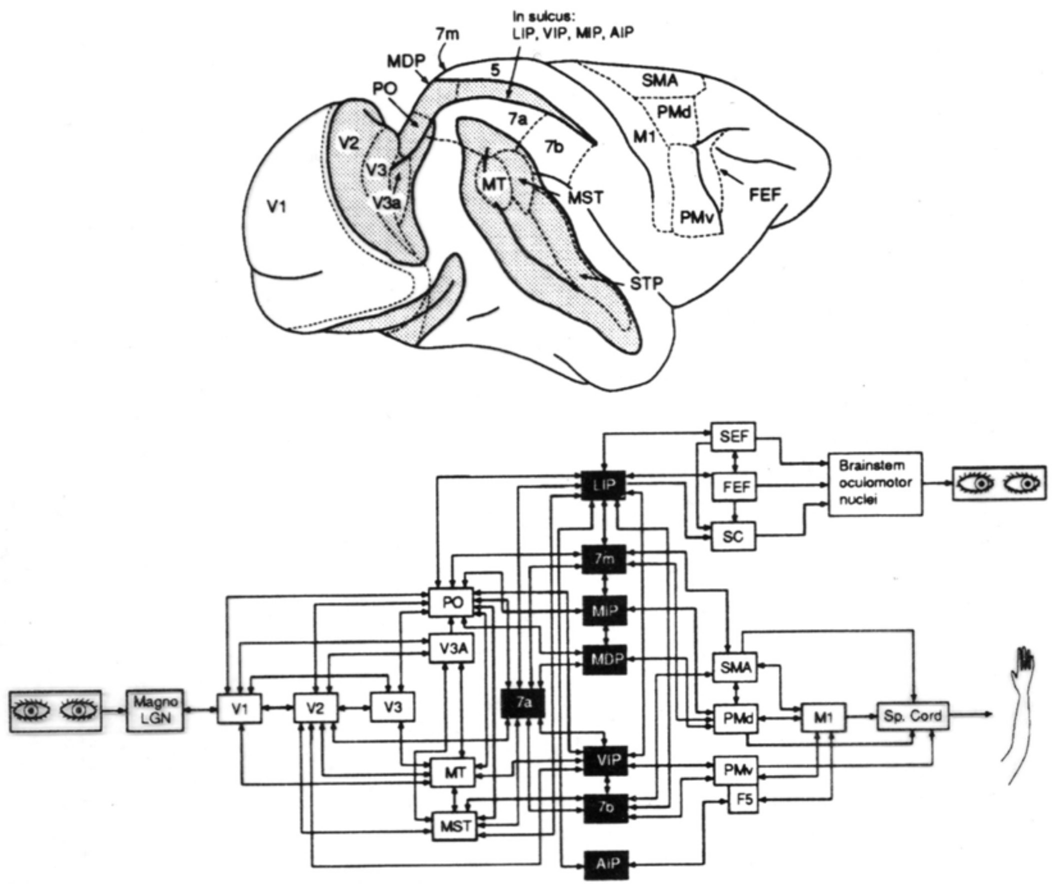
Fig. 4. ***Examples of F5 neurons.*** **(A and B)** *Grasping neurons. The monkey is seated in front of a dark box. The trial started when the monkey pressed a bar. The box was then illuminated and a geometric solid, located inside it, became visible. After a variable time interval, the door of the box opened automatically, and the monkey was allowed to release the bar, and reach for the object. Time plots of neuronal discharge (rasters and histograms), and the distance between the thumb and index finger (recorded with a computerized movement analyzer) are shown. The traces are aligned with the onset of hand movement (vertical bar). Black marks indicate the moment when the door opened. The presented objects were (from left to right) a small sphere, a large sphere, and a horizontally positioned cylinder. Ordinates: spikes bin^{-1}; binwidth, 20 ms.* **(C)** *Grasping neuron with mirror properties. First two panels: an experimenter grasps a raisin in front of the monkey (first discharge), moves it towards the monkey (no discharge), the monkey grasps it (second discharge). Note the difference between hand and tool grasping (pliers). Right panel: same neuron. Monkey grasps an object in the dark.*

SENSORY AND MOVEMENT-RELATED ACTIVITY IN PMv (F5) and M1



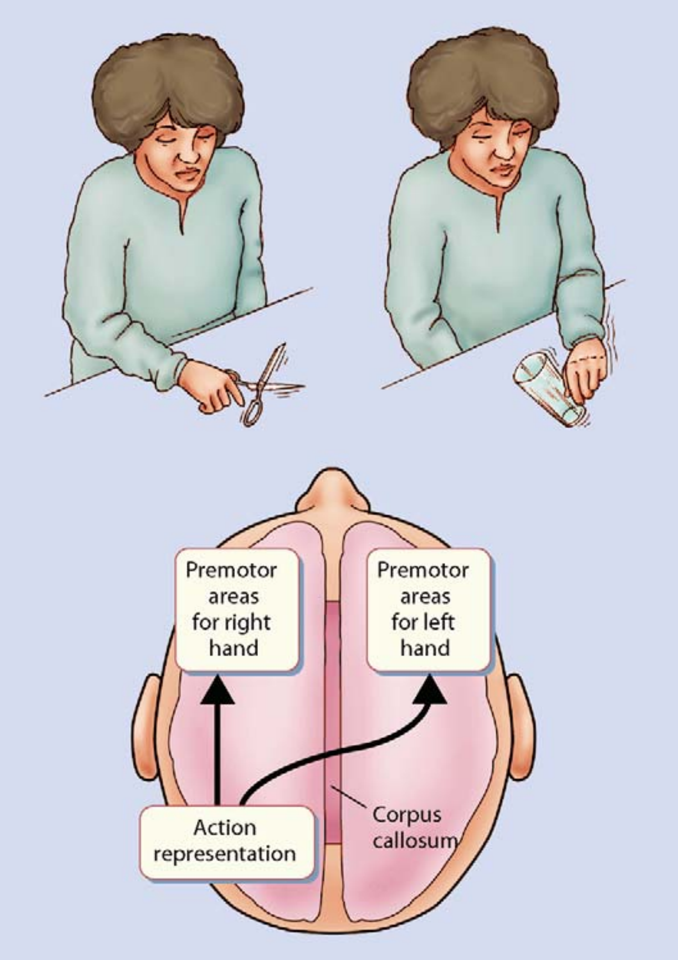
A: Black regions show the tactile receptive fields of 8 M1 neurons recorded at loci where intrarcortical microstimulation evoked flexion of the monkey's index and ring fingers. Other neurons at the same loci responded to passive extension of those fingers (Rosen and Asanuma). **B**: A single PMv neuron 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).

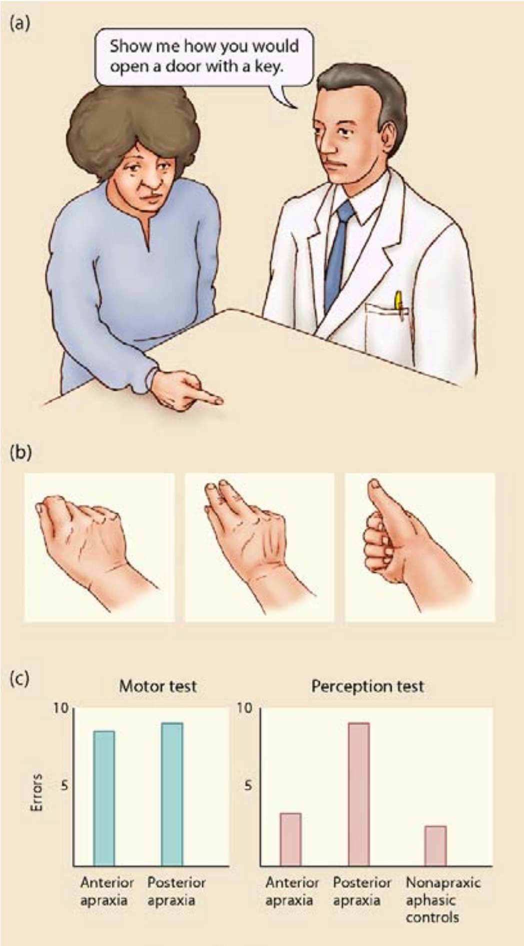
AREAS AND PATHWAYS IN VISUOMOTOR COORDINATION



Visuomotor pathways of the monkey brain. (a) Lateral view of macaque cerebraql cortex showing 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)

APRAXIAS





Patients with apraxias may not be able to recognize skilled movements. (**a**): in the motor test, the patient is asked to pantomime a gesture such as using a key to open a door. (**b**) in the perception test the patient views an actor pantomiming an action in 3 different ways, only one of which is appropriate. The patient must choose which action is corrrect. (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, aphasic control subjects on the perception test (Heilman et al., 1982; Gazzaniga).

Model of the neural regions associated with the production of skilled actions. The premotor area of the contralateral 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).