Motor Cortex

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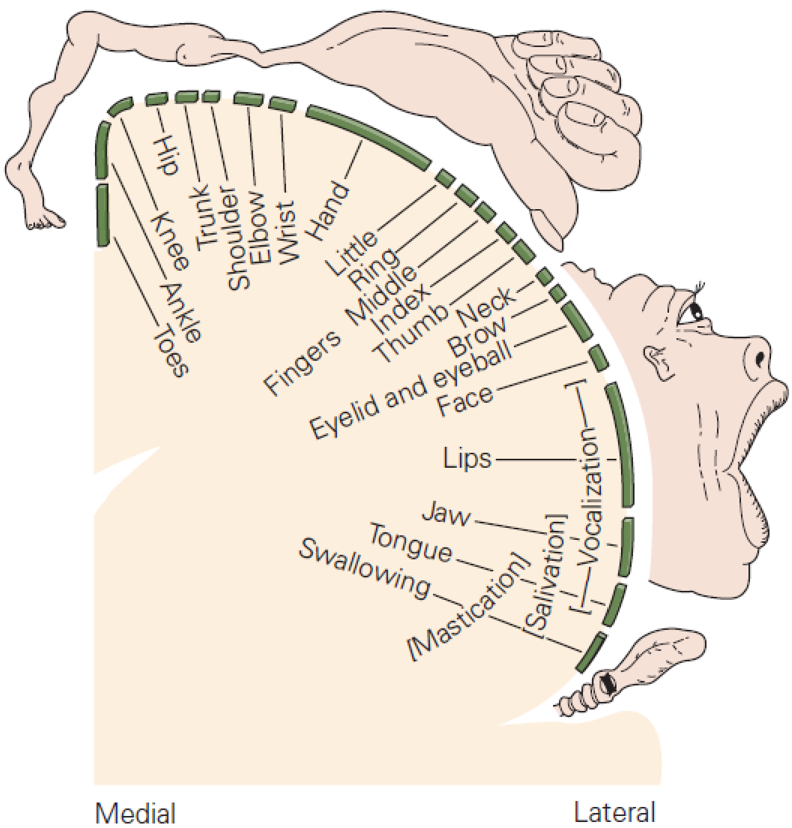
"…. The physiology of movements is basically a study of the purposive activity of the nervous system as a whole." — Gelfand et al., 1966

- ability to use fingers, hands, and arms in ***voluntary actions independent of locomotion*** further helps primates, and especially humans, exploit their environment.
- voluntary movements are ***intentional***—they are initiated by an internal decision to act— voluntary actions involve ***choices between alternatives***, including the choice not to act. Furthermore, they are organized to ***achieve some goal*** in the near or distant future.
- voluntary movements often have a labile, context-dependent ***association with sensory inputs***.
- nature and effectiveness of voluntary movements often ***improve with experience***.

PRIMARY MOTOR CORTEX

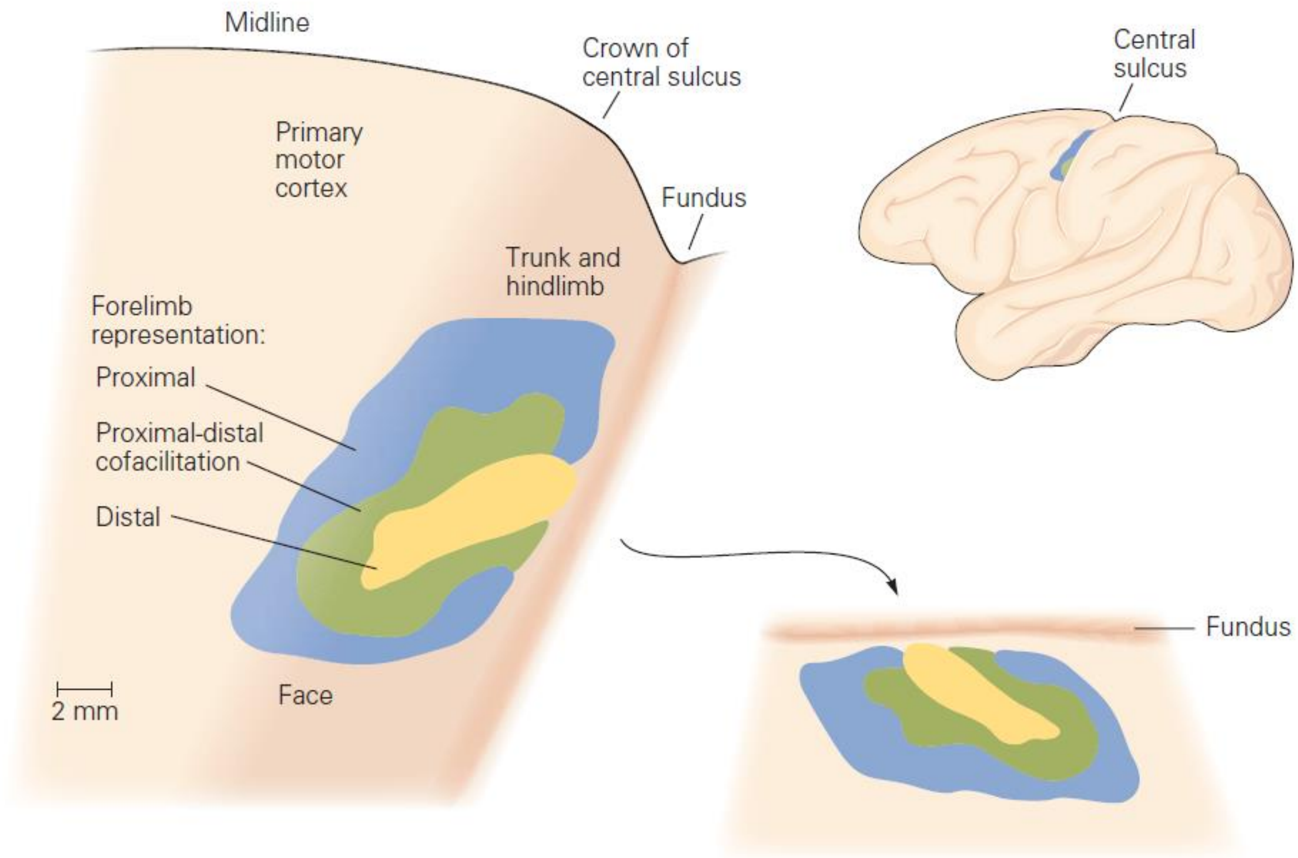
- In the middle of the 19th century the English neurologist John Hughlings Jackson described **Jacksonian March** – focal spread of motor seizures.

Wilder Pen!eld and colleagues - the human motor cortex motor map:

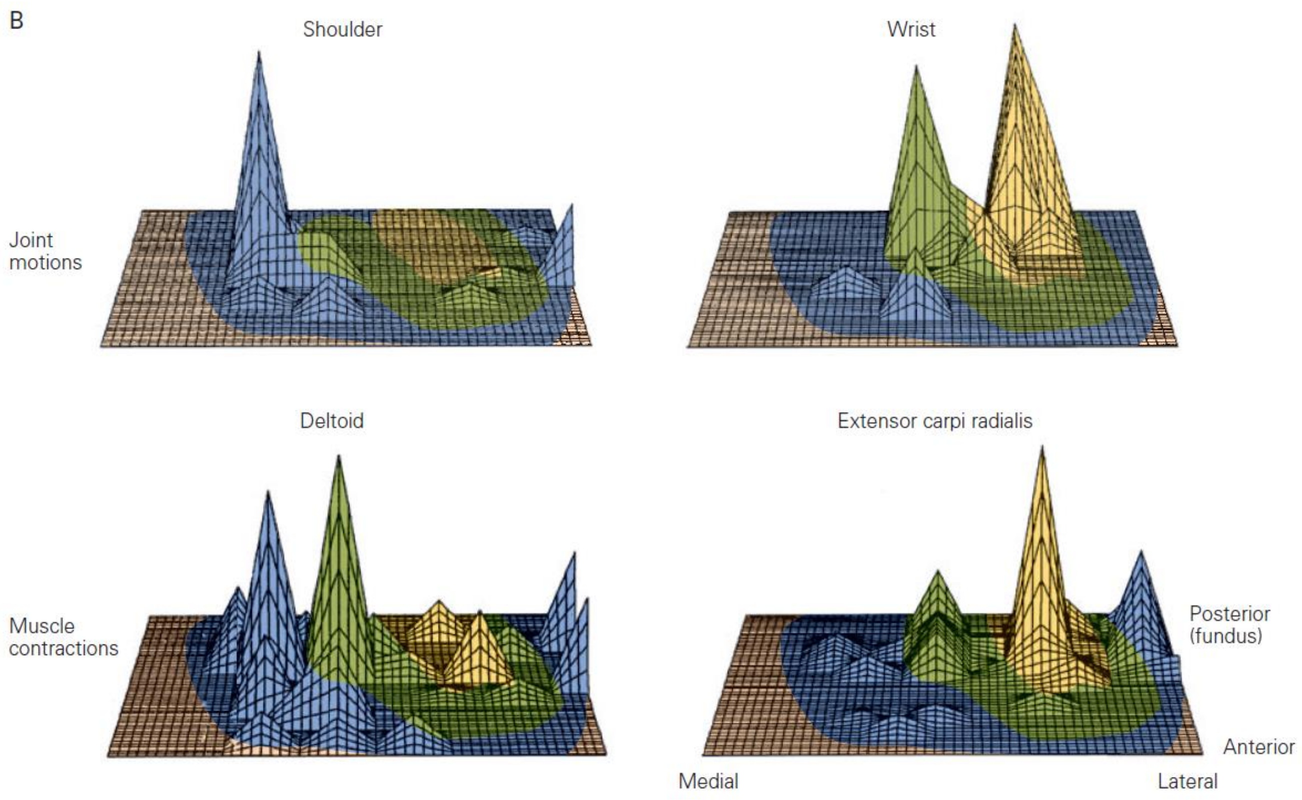


- neurons controlling the muscles of the digits, hand, and distal arm tend to be concentrated within a central zone, whereas those controlling more proximal arm muscles are located in a horseshoe-shaped ring around the central core/

The arm motor map in monkeys has a concentric, horseshoe-shaped organization: Neurons that control the distal arm (digits and wrist) are concentrated in a central core (yellow) surrounded by neurons that control the proximal arm (elbow and shoulder; blue). The neuron populations that control the distal and proximal parts of the arm overlap extensively in a zone of proximal-distal cofacilitation (green). The arm motor representation is seen in its normal anatomical location in the anterior bank of the central sulcus (left), and also after "attening and rotation to bring it into approximate alignment with the microstimulation maps in part B. (Reproduced, with permission, from Park et al. 2001.):

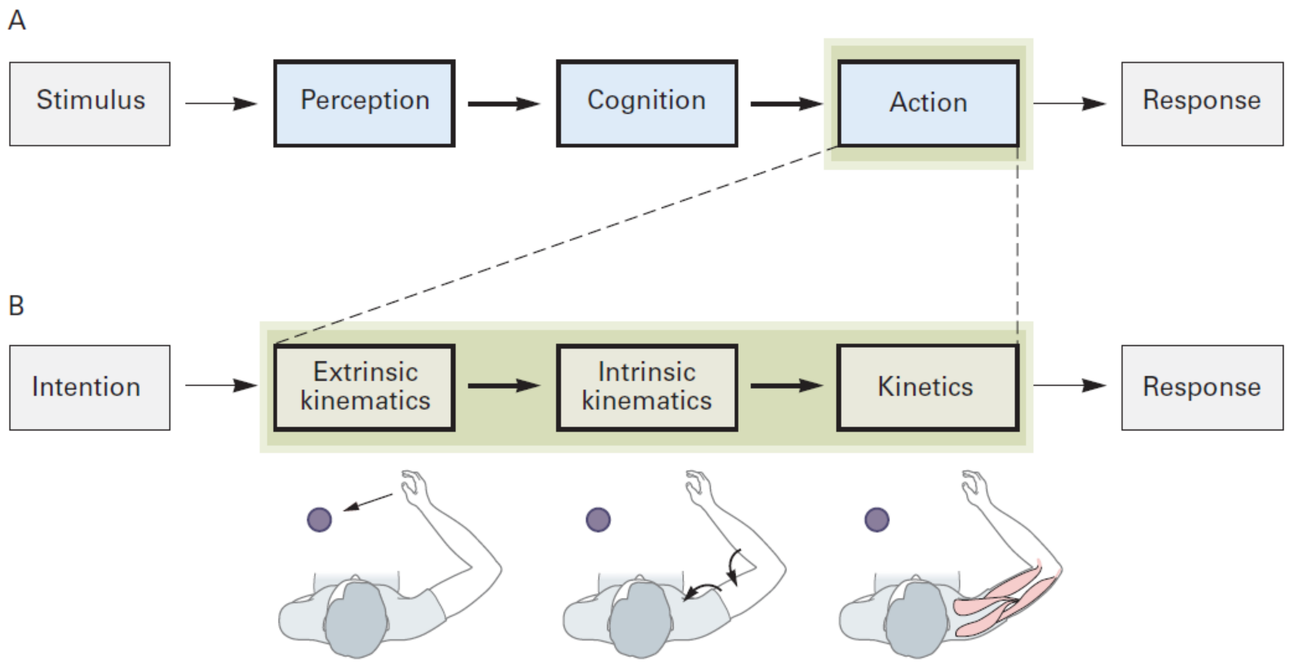


B. Microstimulation of several sites in the arm motor map can produce rotations of the same joint. Neurons that control wrist movements are concentrated in the central core whereas those that regulate shoulder movements are distributed around the core, with some overlap between the two populations. In these maps, the height of each peak is scaled to the inverse of the stimulation current: the higher the peak, the lower the current necessary to produce a response. The distribution and overlap of stimulation sites that evoke contractions of muscles in the shoulder (deltoid) and wrist (extensor carpi radialis) are even more extensive than that of sites for joint rotations. The yellow, green, and blue color zones on these maps correspond only approximately to the functional zones identi!ed in the motor map of part A. (Reproduced, with permission, from Humphrey and Tanji 1991.):



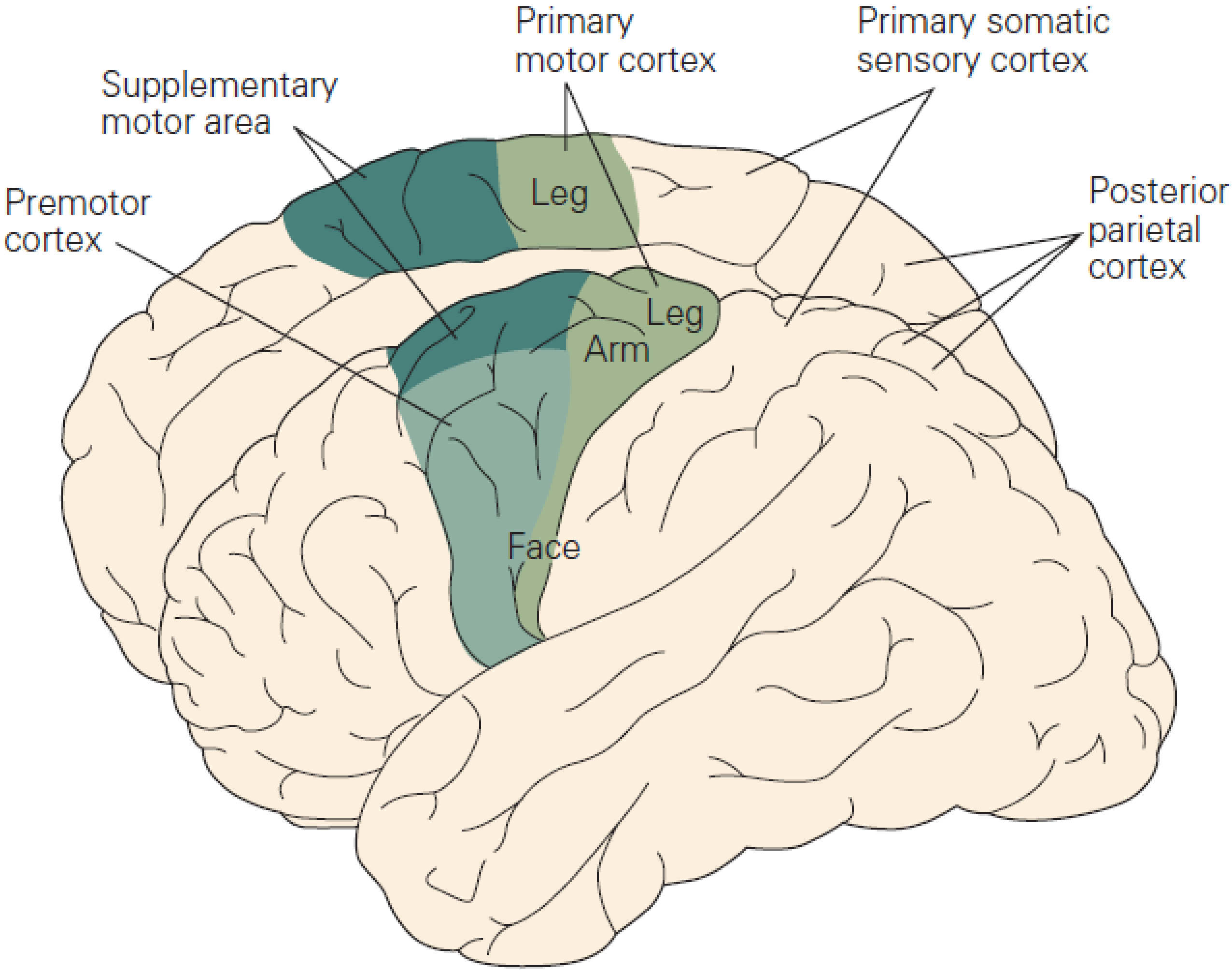
- the neural processes by which the brain controls voluntary behavior are commonly divided into three sequential stages:
  1. First, perceptual mechanisms generate a unified sensory representation of the external world and the individual within it.
  2. Next, cognitive processes use this internal replica of the world to decide on a course of action.
  3. Finally, the selected motor plan is relayed to action systems for implementation

Cortical control of voluntary behavior appears to be organized in a hierarchical series of operations.
A. The brain's control of voluntary behavior has often been divided into three main operational stages, in which perception generates an internal neuronal image of the world, cognition analyzes and reflects on this image to decide what to do, and the final decision is relayed to action systems for execution. However, this three-stage serial organization was largely based on introspective psychological studies rather than on direct neurophysiological study of neural mechanisms.
B. Each of the three main operational stages is presumed to involve its own serial processes. For example, the "action" stage that converts an intention into a physical movement is often presumed to involve a hierarchy of operations that transform a general plan into progressively more detailed instructions about its implementation. The model shown here, inspired by early controller designs for multijoint robots, suggests that the brain plans a chosen reaching movement by first calculating the extrinsic kinematics of the movement (eg, target location, trajectory of hand displacement from the starting location to the target location), then calculating the required intrinsic kinematics (eg, joint rotations) and finally the causal kinetics or dynamics of movement (eg, forces, torques, and muscle activity):



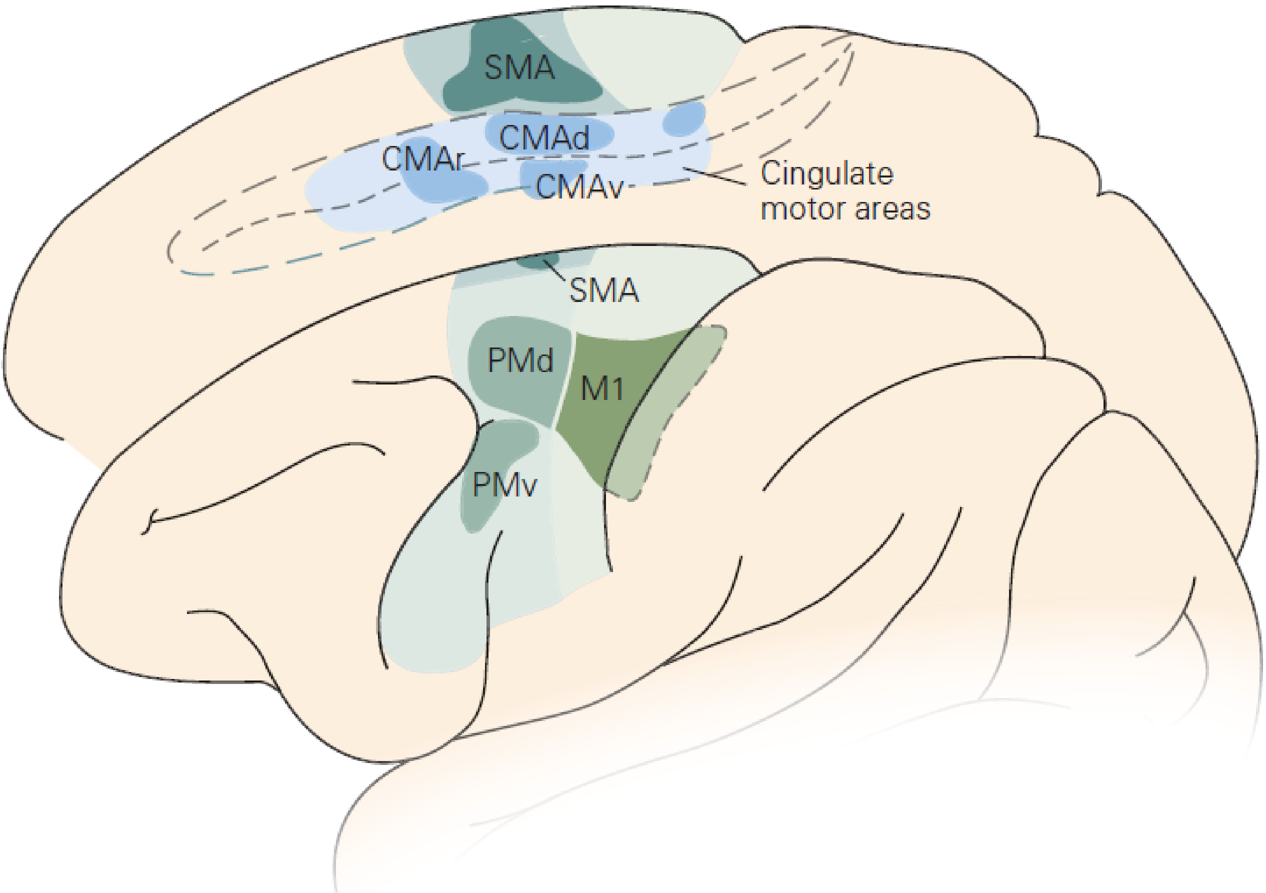
- Alfred Campbell and Korbinian Brodmann:
  - divided the human cerebral cortex into a large number of cytoarchitectonic areas with distinct anatomical features; they noted that the precentral cortex in the gyri immediately rostral to the central sulcus lacks the six layers characteristic of most cerebral cortex - it lacks a distinct internal granule cell layer and thus is often called ***agranular cortex***.
  - subdivided the precentral cortex into caudal and rostral parts, which Brodmann designated cytoarchitectonic areas 4 and 6.

Based on their histological studies at the beginning of the 20th century, Korbinian Brodmann and Alfred Campbell each divided the precentral cortex in humans into two anatomically distinct cytoarchitectonic areas: the primary motor cortex (Brodmann's area 4) and premotor cortex (Brodmann's area 6). Subsequent studies by Woolsey and colleagues led to subdivision of the premotor cortex into medial and lateral halves, the supplementary motor area and lateral premotor cortex, respectively:



- motor map of different body parts evoked by stimulation of the supplementary motor area is less detailed than that of the primary motor cortex and lacks the enlarged distal arm and hand representation seen in the primary motor cortex. Stimulation of the supplementary motor area can evoke movements on both sides of the body or halt ongoing voluntary movements, effects that rarely result from stimulation of the primary motor cortex.

Neurons that modulate muscle activity in the contralateral arm and hand originate in the primary motor cortex (M1) and many subdivisions of the premotor cortex (PMd, PMv, SMA) and project their axons into the spinal cord cervical enlargement. Corticospinal !bers projecting to the leg, trunk, and other somatotopic parts of the brain stem and spinal motor system originate in the other parts of the motor and premotor cortex. (M1, primary motor cortex; SMA, supplementary motor area; PMd, dorsal premotor cortex; PMv, ventral premotor cortex; CMAd, dorsal cingulate motor area; CMAv, ventral cingulate motor area; CMAr, rostral cingulate motor area.):



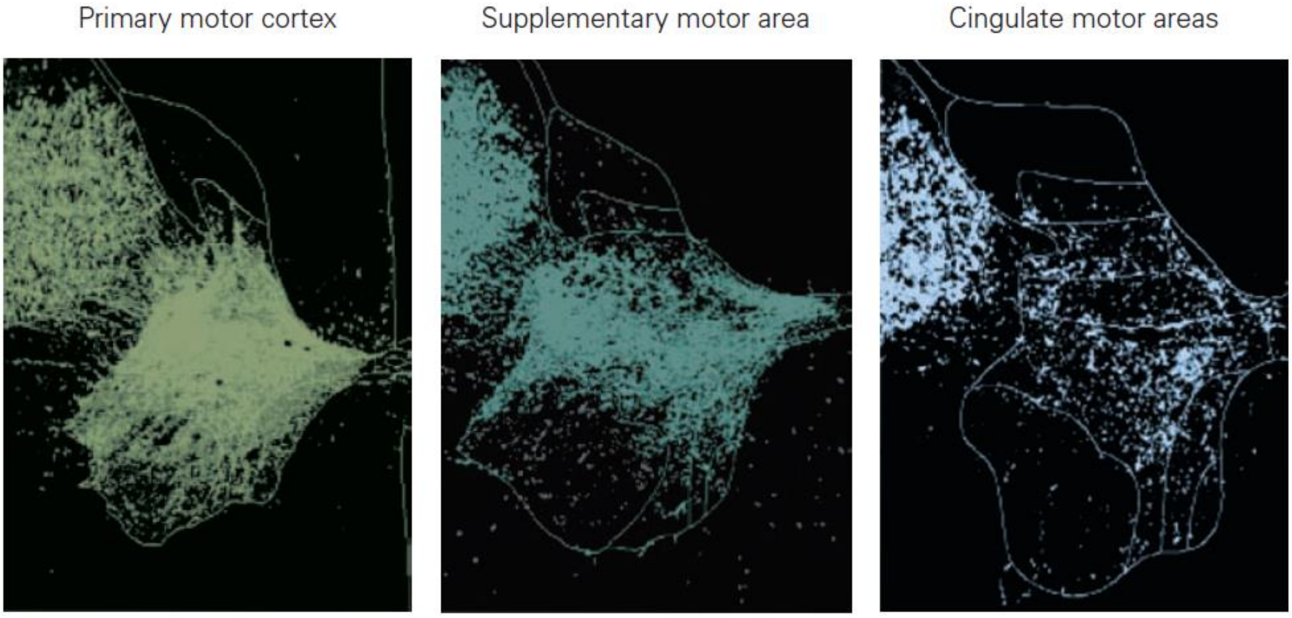
Many primary motor cortex neurons receive sensory input from proprioceptors or cutaneous mechanoreceptors. The tactile input is particularly prominent on neurons implicated in the control of hand and digit movements. These inputs inform the motor system about the current state of the body, such as the position, posture, and movement of the arm and hand and their interactions with the environment. This information can play at least three functional roles: in feedback control of ongoing movements, in feed- forward control of intended movements, and as a teaching signal during motor learning.

PYRAMIDAL TRACT

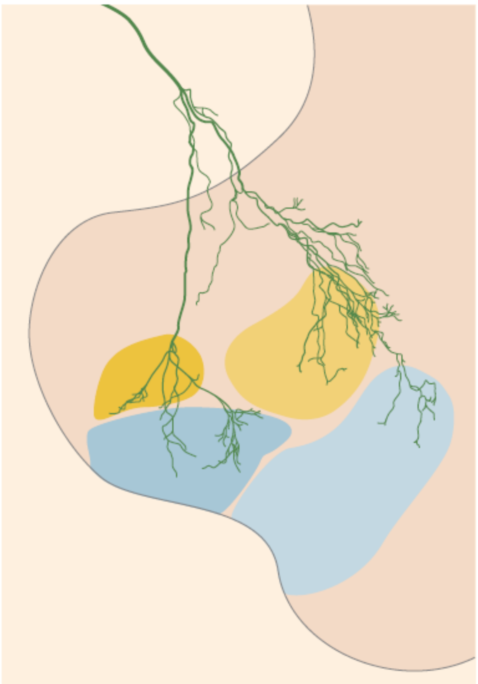
- pyramidal tract originates in cortical layer V in a number of precentral and parietal cortical areas. Precentral areas include not only primary motor cortex but also the supplementary motor and dorsal and ventral premotor areas. The pre-supplementary motor and pre-dorsal premotor areas do not send axons to the spinal cord; their descending output reaches the spinal cord indirectly through projections to other subcortical structures.
- parietal areas that contribute descending axons to the pyramidal tract include the primary somatosensory cortex and adjacent rostral parts of the superior and inferior parietal lobules.

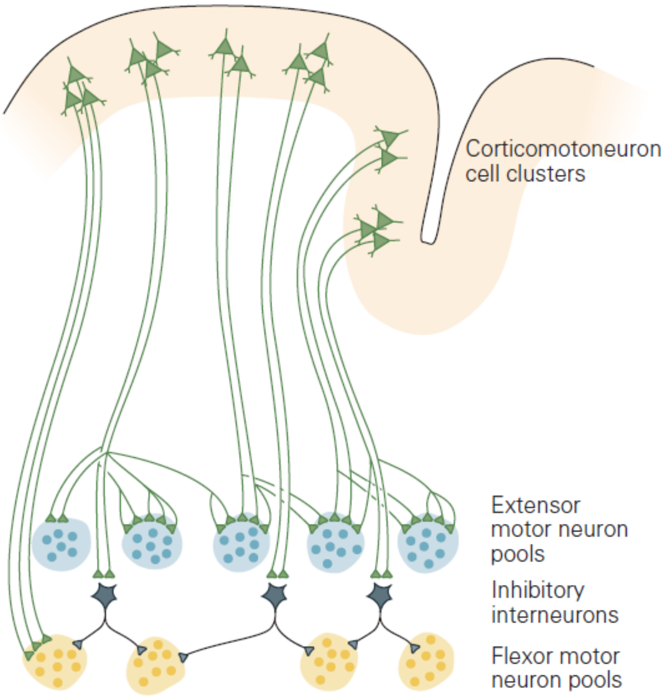
N.B. several premotor and parietal areas of cortex can also influence spinal motor function through their own corticospinal projections!
The traditional view that the primary motor cortex is the “final common path” from the cerebral cortex to the spinal cord is incorrect!

The axons of corticospinal fibers from the primary motor cortex, supplementary motor area, and cingulate motor areas terminate on interneuronal networks in the intermediate laminae (VI, VII, and VIII) of the spinal cord. Only the primary motor cortex contains neurons whose axons terminate directly on spinal motor neurons in the most ventral and lateral part of the spinal ventral horn. Rexed's laminae I to IX of the dorsal and ventral horns are shown in faint outline. The dense cluster of labeled axons adjacent to the dorsal horn (upper left) in each section are the corticospinal axons descending in the dorsolateral funiculus, before entering the spinal intermediate and ventral laminae.



- much of the control exerted by the primary motor cortex on spinal motor circuits and all of the control from premotor areas is mediated indirectly through these descending cortical projections to spinal interneurons.
- terminals of some corticospinal axons also extend into the ventral horn of the spinal cord (lamina IX) where they arborize and contact the dendrites of spinal motor neurons - these monosynaptically projecting cortical neurons are called ***corticomotoneurons***.
- frequently, a single corticomotoneuron axon directly excites the spinal motor neurons for several agonist muscles and indirectly suppresses the activity of some antagonist muscles through local inhibitory interneurons:



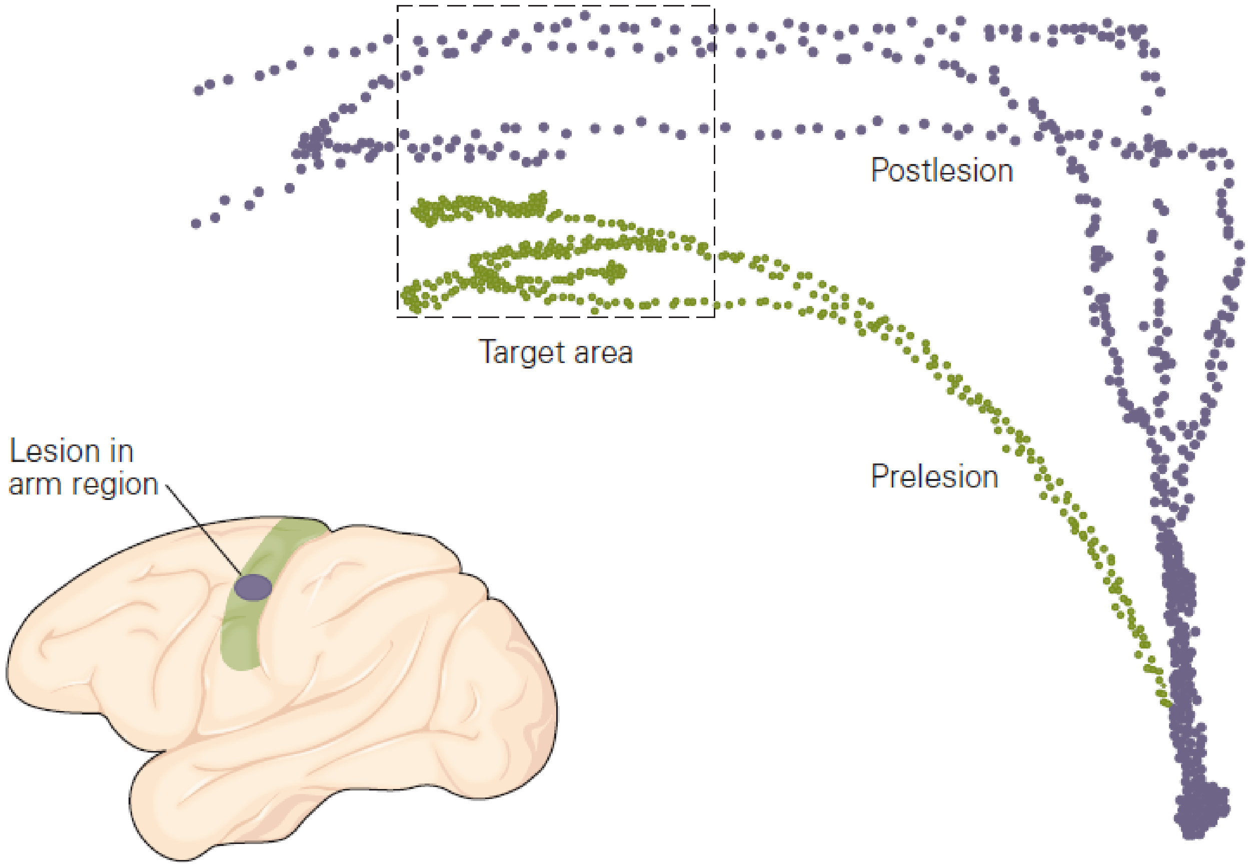


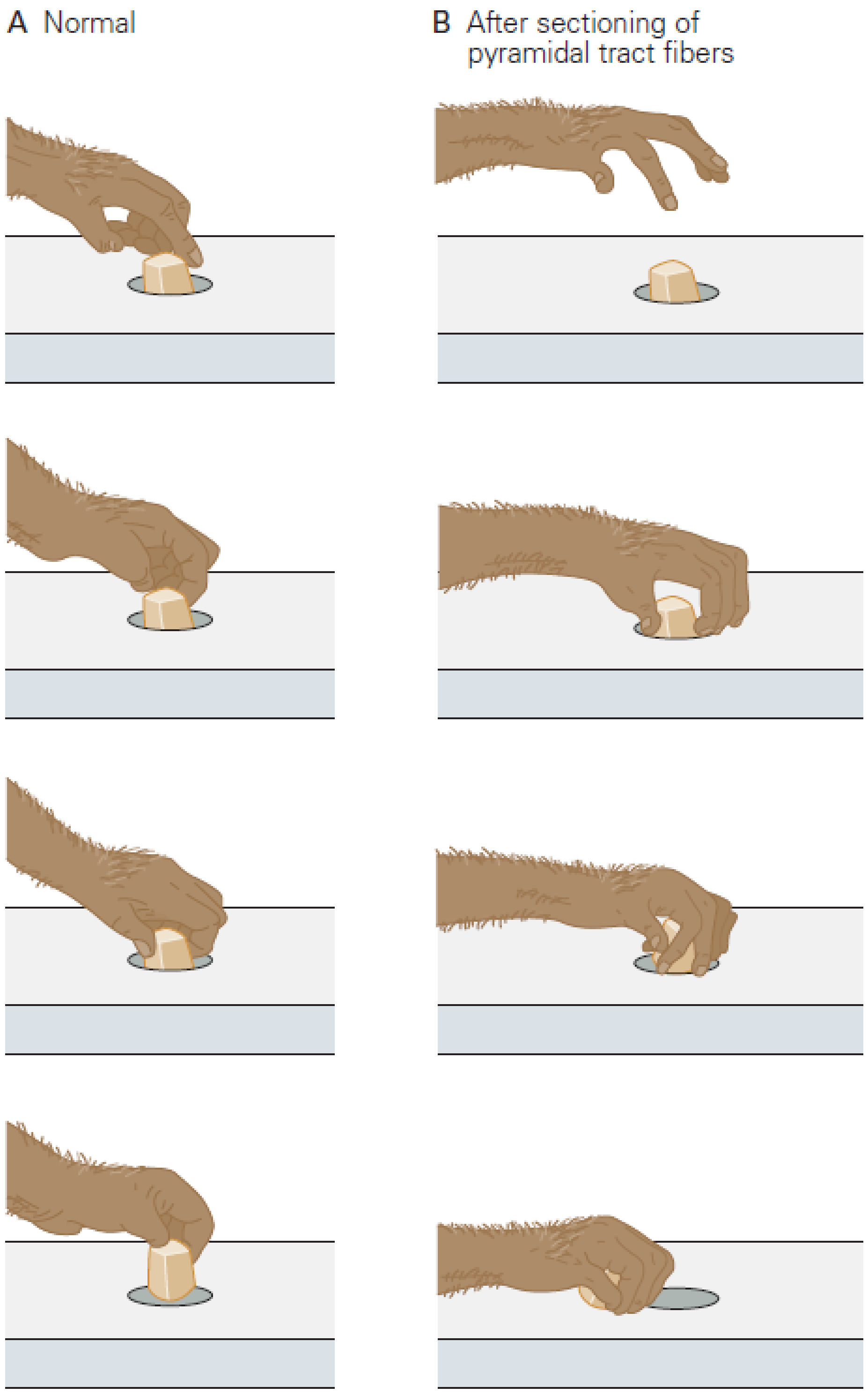
- the fact that corticomotoneurons are more prominent in humans than in monkeys may be one of the reasons why lesions of the primary motor cortex have such a devastating effect on motor control in humans compared to lower mammals.

N.B. *spinal cord also receives inputs* from the rubrospinal, reticulospinal, and vestibulospinal tracts - influence movement through monosynaptic terminations onto spinal interneurons and spinal motor neurons!

PREMOTOR CORTEX

- focal lesions of premotor areas cause a variety of more selective deficits that do not result from an inability to perform individual actions but rather an inability to choose the appropriate course of action (e.g. lesions of the ventral premotor cortex perturb the ability to use visual information about an object to shape the hand appropriately for the object's size, shape, and orientation before grasping it).


Target area
Postlesion
Prelesion
Lesion in
arm region



BIBLIOGRAPHY for ch. "Cerebrum" → follow this LINK >>
Eric R. Kandel, James H. Schwartz "Principles of Neural Science" 5th ed. (2013); Publisher: McGraw-Hill Medical; ISBN-10: 0071390111, ISBN-13: 978-0071390118 (ch. 37) >>