Hierarchical Levels of Motor Control

Cortex: Directional & intentional, task oriented, fine muscle movements, visually oriented, learned skills

↓

Brainstem (e.g. vestibular system): complex coordination of muscle groups, eg. Oculomotor, postural responses -- learned responses like vestibular adaptation

↓

Central Pattern generator: fires multiple muscles rhythmically over time to carry out complex movement

↓

Spinal Motor neuron: fires one muscle, responds to reflex

Anatomy of Motor Cortex

Located on rostral side of central sulcus
(across from somatosensory cortex)

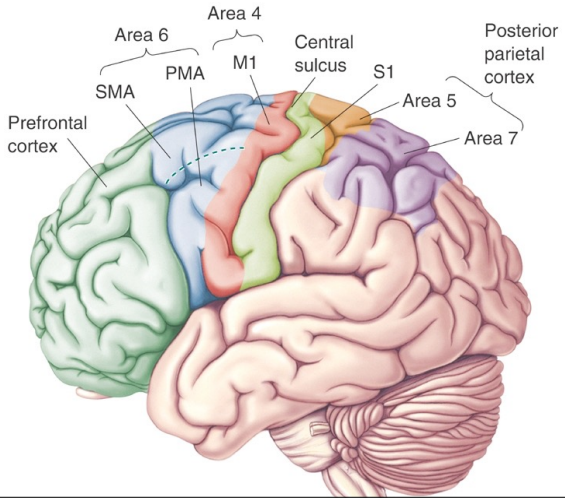
M1
Primary motor cortex - simple features of movement

PMA
Premotor area - visually guided, fine finger movements

SMA
Supplemental Motor Area -- planned, trained, or practiced movements

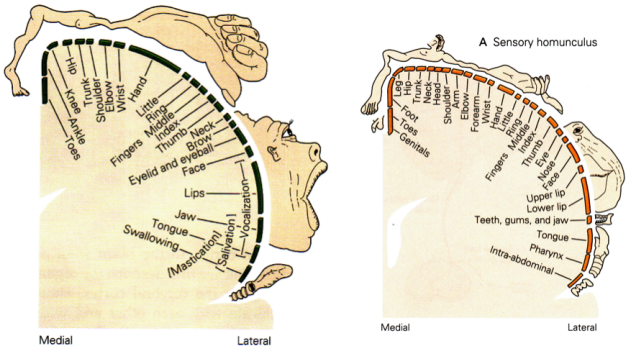
Motor cortical areas are organized somatopically.

Anatomy of Motor Cortex

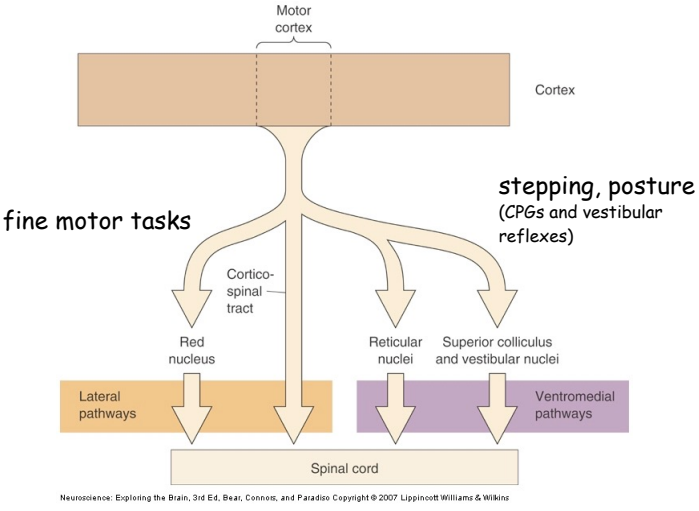


Homunculus in Motor & Sensory Cortex

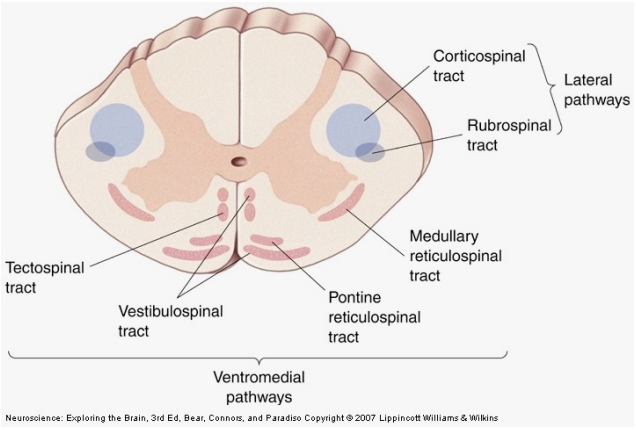
Motor **Sensory**



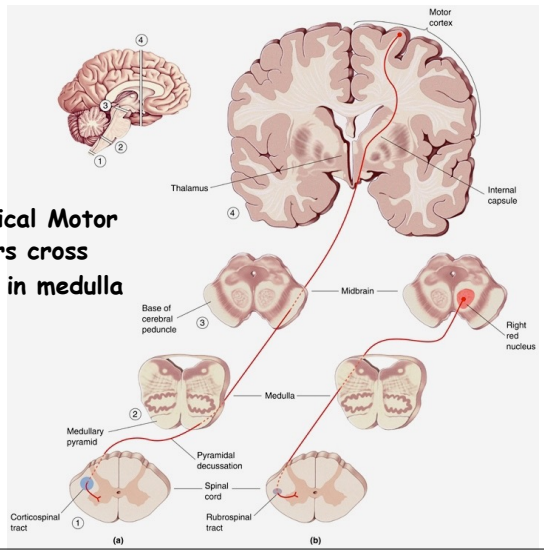
Motor Homunculus



"lateral voluntary pathways"



Cortical Motor fibers cross over in medulla



Stimulation of Primary Cortex

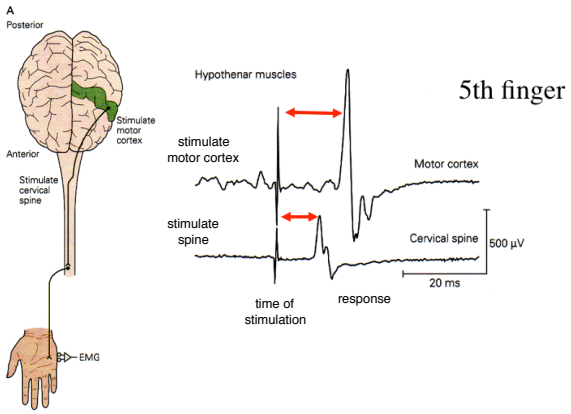
Fritsch & Hitzig
Electical stimulation of motor cortex of dogs (and wounded soldiers)

Hughlings Jackson
Jacksonian march of focal seizures -- random neural activity sweeping the surface of the motor cortex

M1 stimulation:
easy to stimulate, large simple limb movements

Premotor stimulation:
takes more juice, fine multi-jointed motor responses

Stimulation of Primary Motor Cortex



Transcranial Magnetic Stimulation

Induction of electrical activity in the motor cortex by magnetic pulse through the skin and skull

Inputs & Outputs of Motor Cortex

Primary Motor Cortex M1

Input: Primary Somatosensory Cortex (so M1 cells have receptive fields)

Input: Premotor Cortex

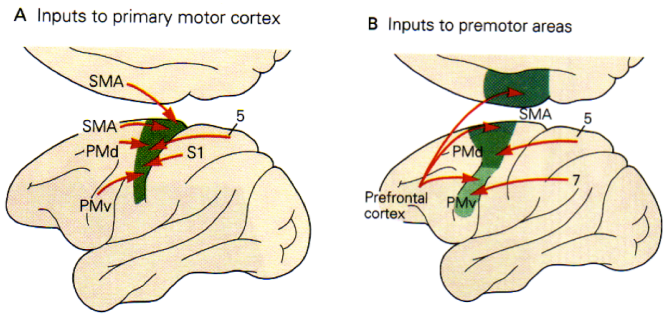
Output: spinal cord, subcortical areas

Premotor Cortex

Input: Prefrontal cortex, Dorsal visual-motor pathway for reaching & grasping

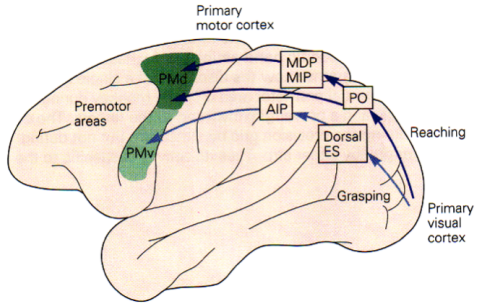
Output: spinal cord, M1 cortex, subcortical areas

Inputs to Motor Cortex



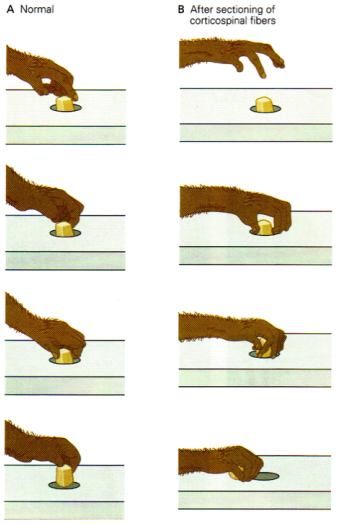
Prefrontal cortex = consciousness?

Dorsal Visual Motor Pathways



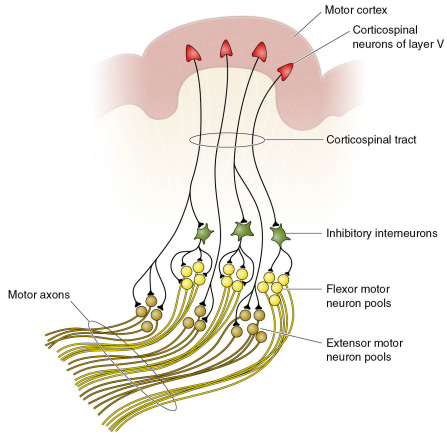
Remember: dorsal = visual-motor tasks, ventral = object recognition

Direct Cortical-Spinal Connections control fine movement

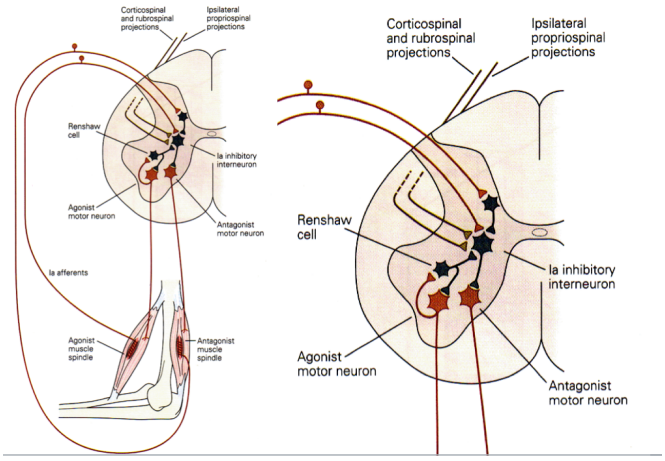


(Indirect cortical-brainstem-spinal connections control gross movements)

Corticospinal Tract Axons Control Pools of Spinal Motor Neurons



Direct cortical-spinal connections modulate spinal reflexes



Firing in individual cortical motor neuron

How does motor cortex activity relate to movement?

Rate of firing proportional to muscle force

but individual cells fire best when moving in specific direction

Population vector (sum of direction of cells x firing rate) predicts direction of movement.

Broadly-tuned cells fire when muscles used to move an object (regardless of direction).

Firing related to motor task, not specific muscles

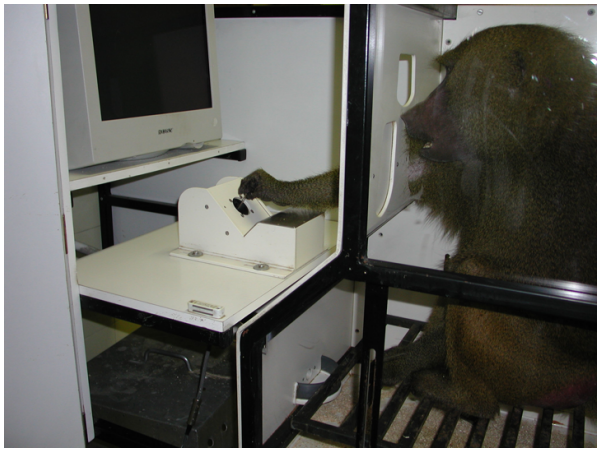
Firing in individual cortical motor neuron

Put electrode into motor cortex

Record from a single cortical motor neuron

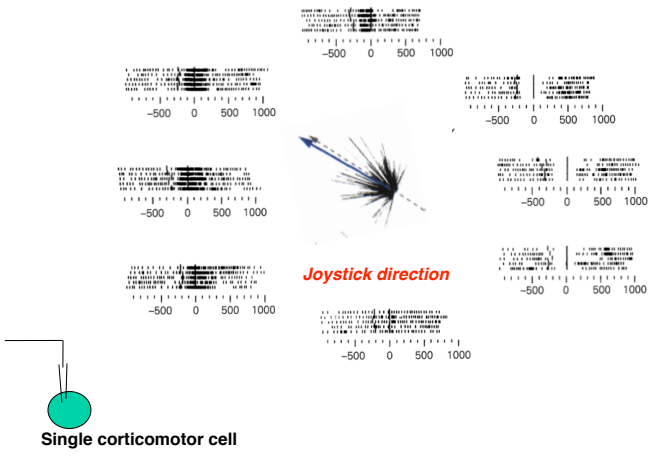
Have the monkey carry out a motor task

Observe the firing pattern of the cortical motor neuron

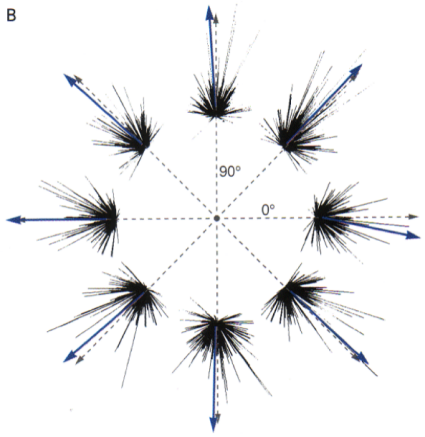


http://gsc.up.univ-mrs.fr/gsite/document.php?pagendx=9451&project=lpc

Single directional cell

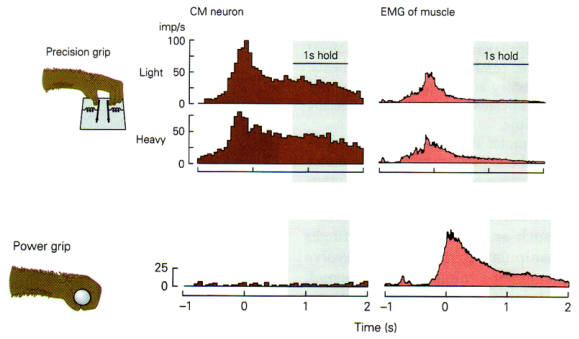


Population of directional cells



Corticomotor neuron activity correlates with task, not muscle

(vs. firing of spinal motor neuron causes contraction of specific muscle)



Firing in premotor cortical neuron

Record from a single premotor cortical neuron and a single primary cortical neuron

Have the monkey carry out a motor task

Observe the timing of the firing of premotor vs motor cortical neurons

Sequential firing of PMA and SMA prior to motor neuron

PMA = visual task, SMA = trained (learned repetition) task

Some PMA neurons fire when task is only imagined or observed (mirror neurons)

Premotor Area Neurons involved in planning movement
ready (red panel), set (blue button), go (touch button)

Premotor Area Neurons involved in planning movement
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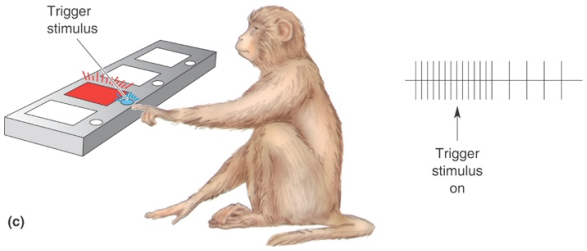
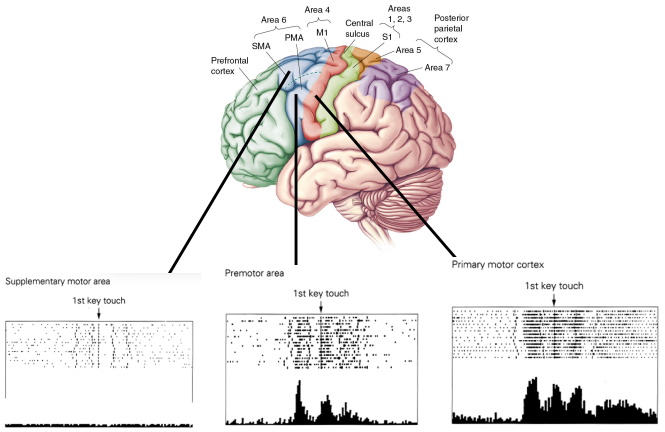
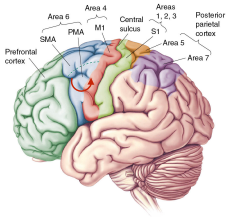
Premotor Area Neurons involved in planning movement
ready (red panel), set (blue button), go (touch button)

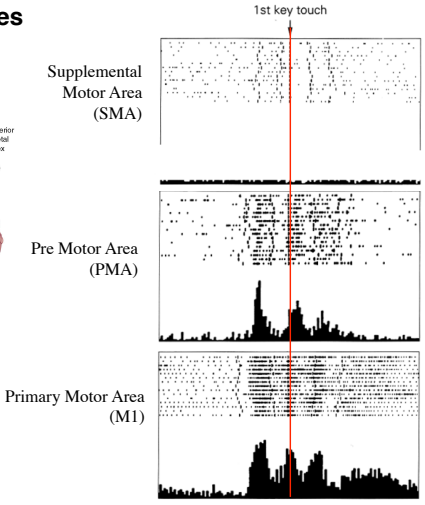


Sequential firing of Premotor Area Neurons, then Primary Motor Neurons

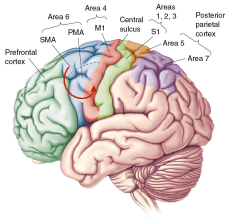


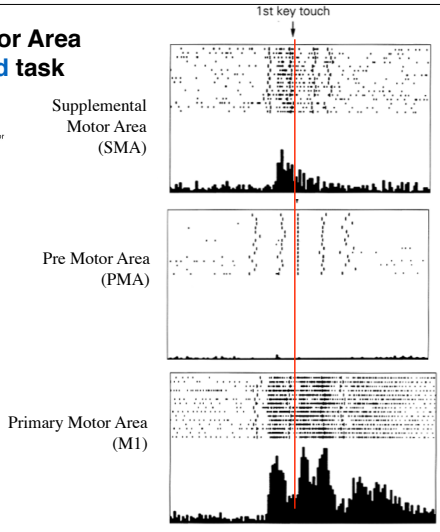
Premotor Cortex fires during visual task





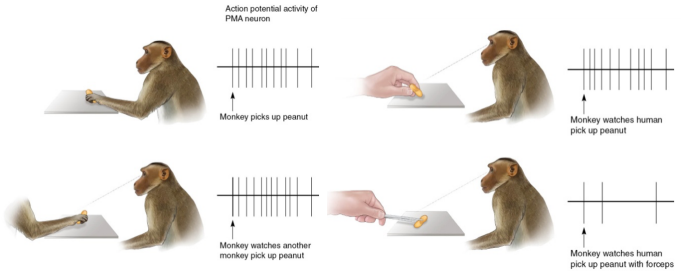
Supplemental Motor Area fires during trained task



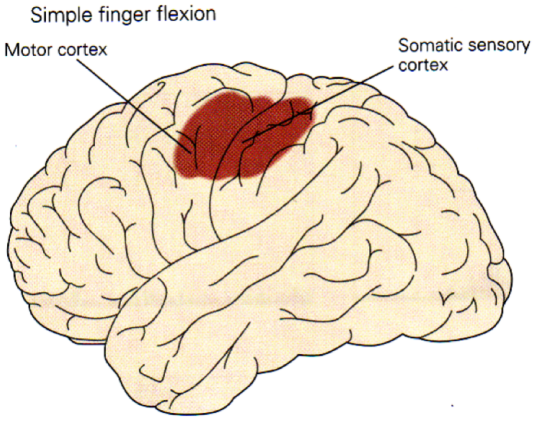


Mirror Neurons in Premotor cortex

- Some neurons in cortical area 6 respond when movement is only imagined.
- Very likely that humans also have mirror neurons
- May be part of extensive brain system for understanding actions and intentions of others



Areas of Cortex respond to simple, complex, and imagined movements



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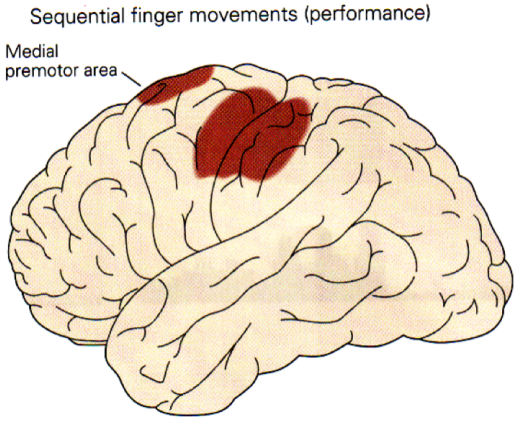
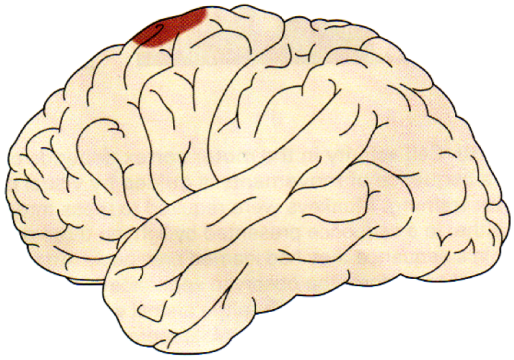


Areas of Cortex respond to simple, complex, and imagined movements

Mental rehearsal of finger movements



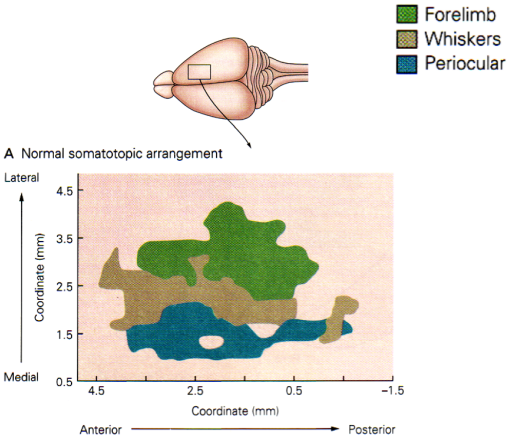
Plasticity of Motor Cortex

Cutting sensory input from a body region causes reorganization of somatotopic map within a few hours

(adjacent motor cortex appears to spread into denervated area -- probably revealing pre-existing overlapping neurons)

Practice enlarges the area of motor cortex involved in a task

Plasticity of Somatotopic Mapping



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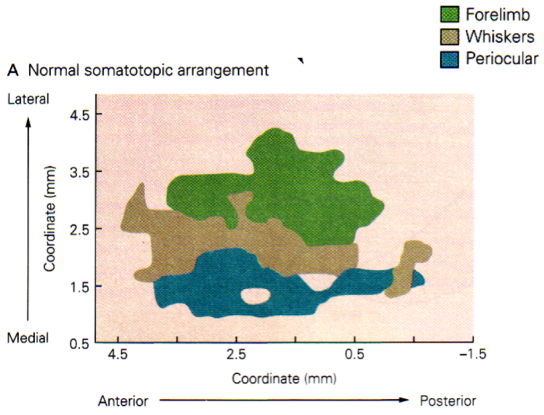

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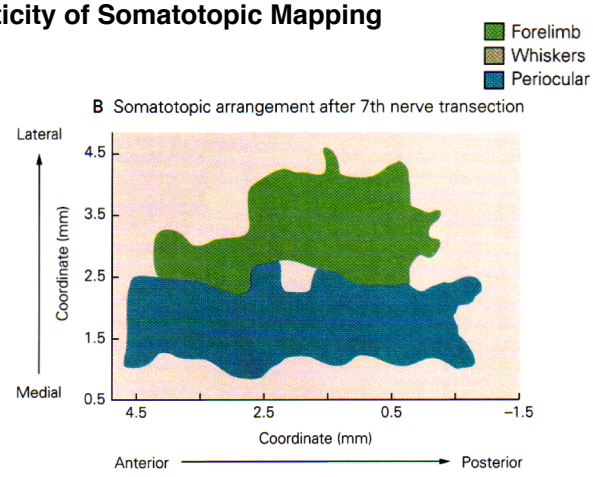
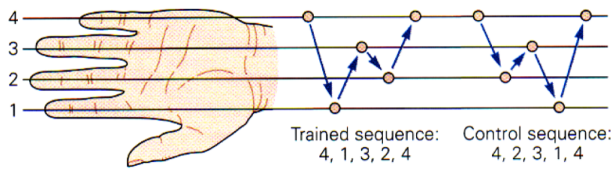
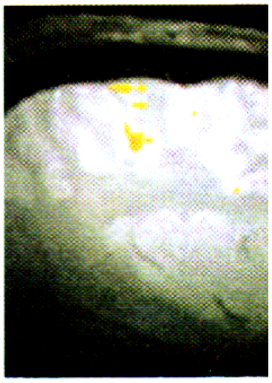


Area of Activated Cortex increases as skill level increase

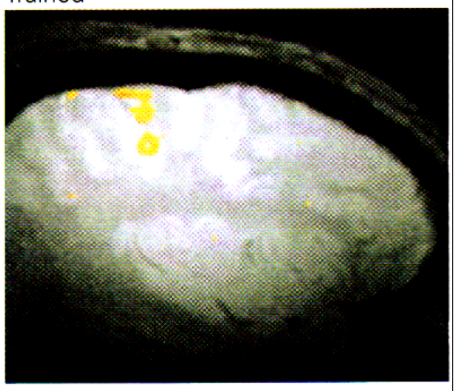


Area of Activated Cortex increases as

Control



Trained



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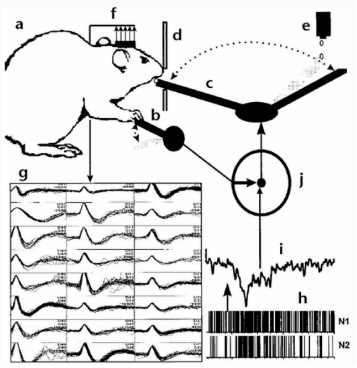
Rat robot



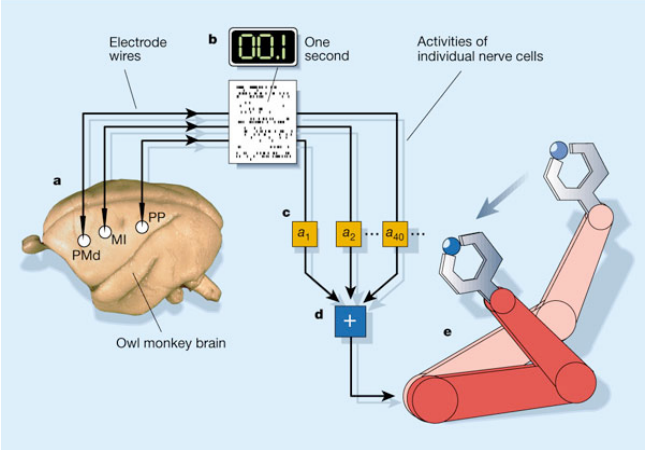
Train rat to bar press for water

Listen to motor cortex until computer can predict pattern preceding bar press

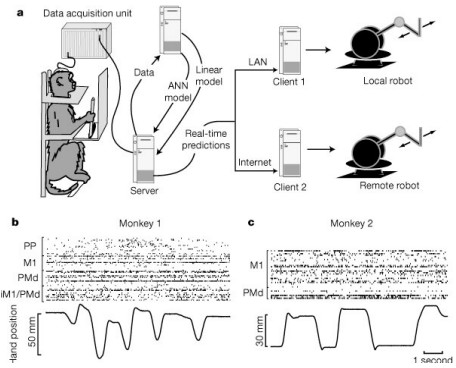
Computer presses bar just before rat gets to it

Rat eventually stops pressing bar, just thinks about pressing it!

Building a robot



Building a robot



https://www.youtube.com/watch?v=ZIIffTH5D-E