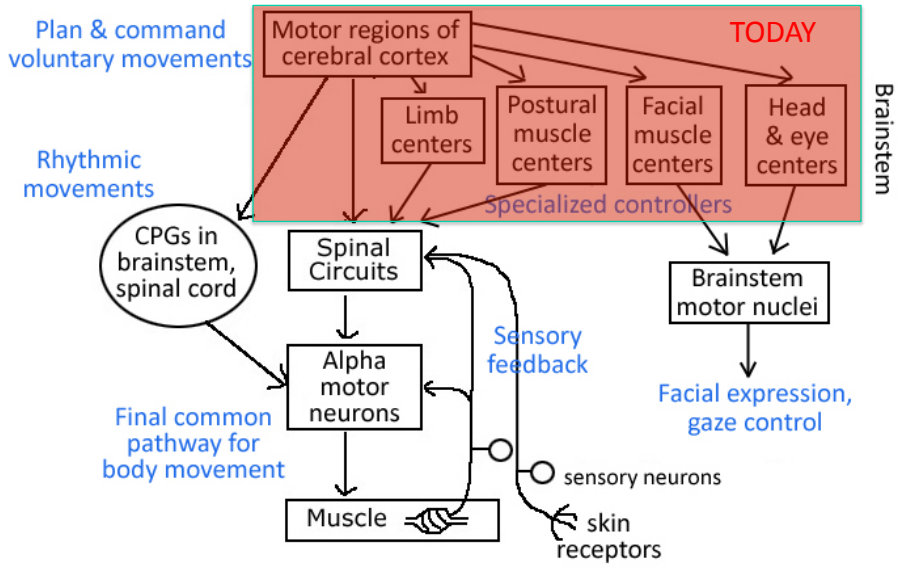
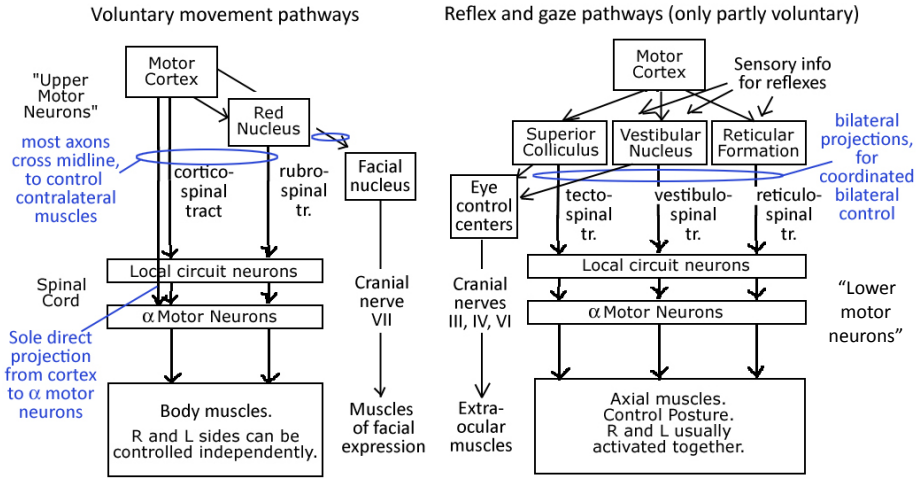
Motor cortex and voluntary movement



1

Parallel descending pathways for different types of movement



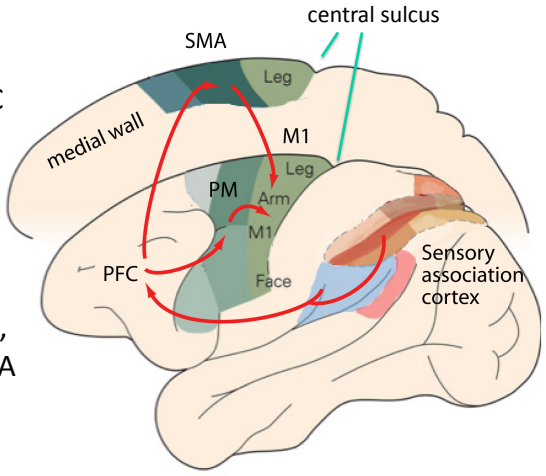
Rest of lecture focuses on simplest pathway, motor cortex → spinal cord → voluntary control of limb movement.

Planning a movement

Decision to move (based on cognitive set, motivation, sensory perception) — PFC

Movement planning (flexible strategy, learned strategies, complex sequences) — PM, SMA

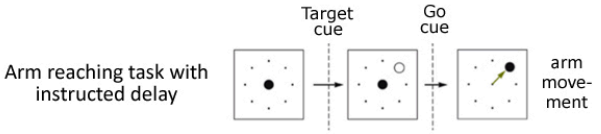
Execution — M1



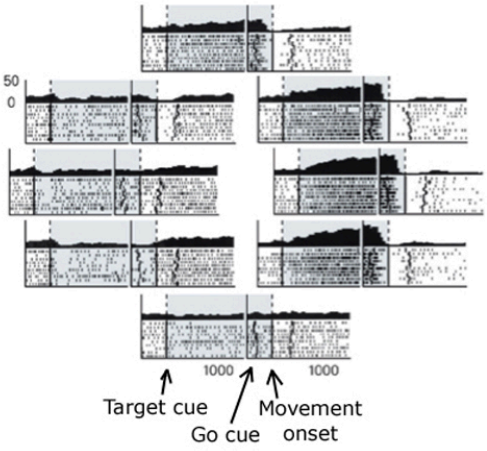
M1. Primary motor cortex. Execution.
SMA. Supplemental motor cortex. Planning.
PM. Premotor cortex. Planning.
PFC. Prefrontal cortex. Cognitive, decision making.

3

Premotor cortex is active during movement planning

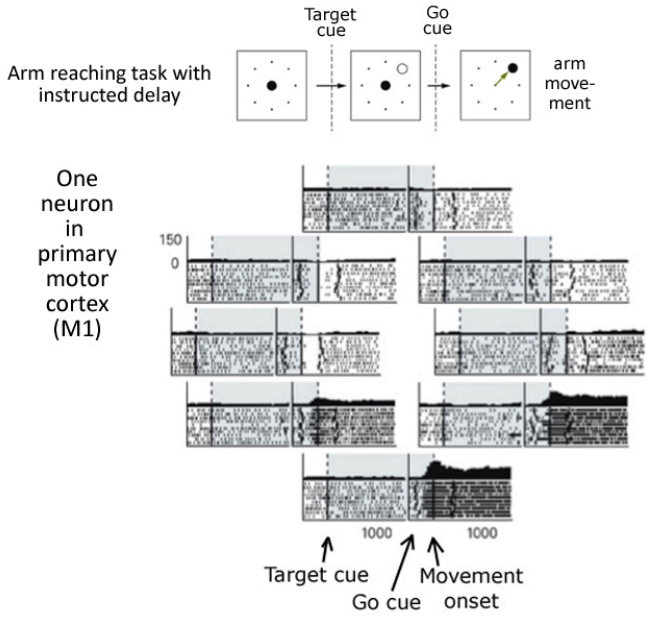


One neuron in dorsal premotor cortex (PM)



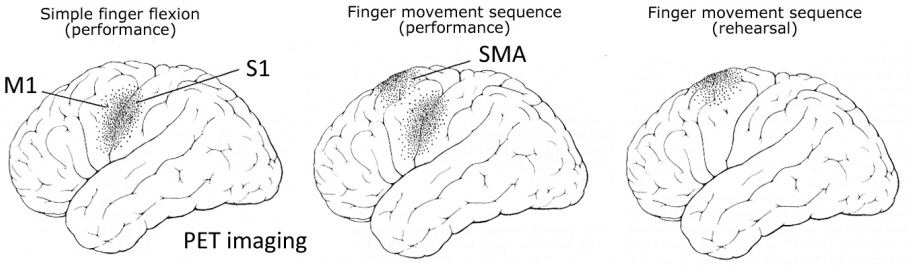
Cisek et al., 2003

Primary motor cortex (M1) is active during movement execution



Cisek et al., 2003

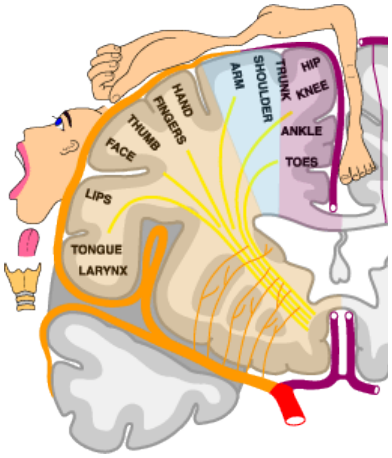
SMA plans complex movement sequences



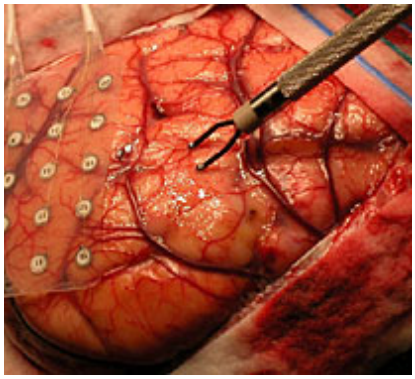
Distinct areas within PM are specialized for different classes of movement, such as reaching, grasping, and defensive arm motions; and for language (Broca's area).

Focal electrical stimulation in PM drives **complex movement gestures**, like bringing food to the mouth or reaching to specific locations.

Motor map in M1 cortex



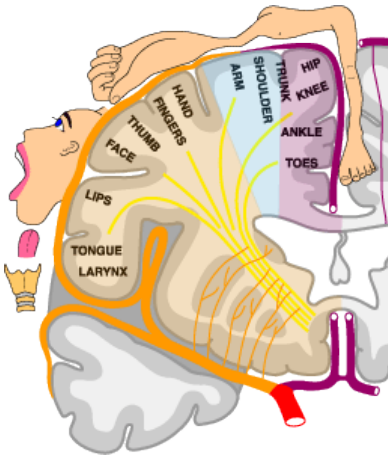
Intracortical stimulation

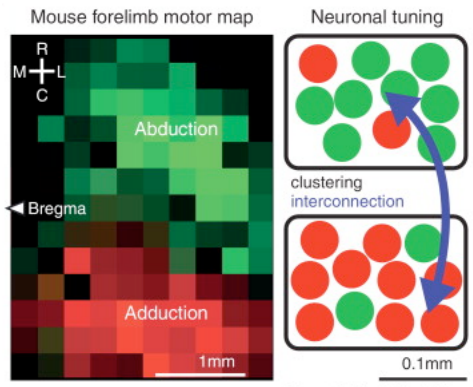


W. Penfield, 1940s-1950s

Brief M1 stimulation evokes small movements of specific contralateral body parts. These are single limbs or single joints, but not single muscles.

Motor map in M1 cortex



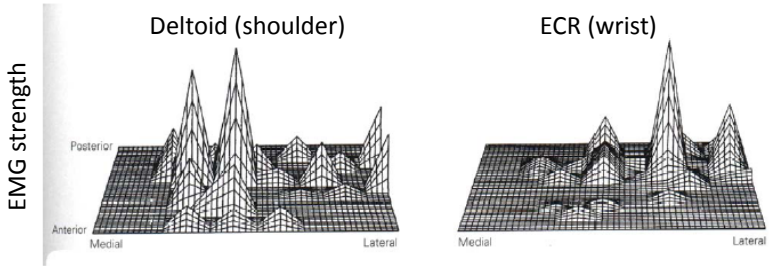


Harrison & Murphy, 2014

Map topography is not exact and continuous, but patchy and irregular. Local zones for limb extension, flexion, etc.

Motor map in M1 cortex

Each M1 locus does not control a single muscle, but a group of inter-related muscles that together move a body part or joint.

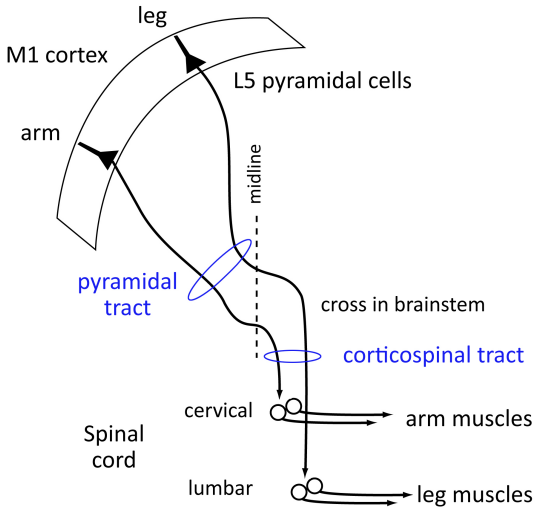


Experiment: Stimulate a grid of M1 locations, while recording electro-myelogram (EMG) from deltoid and ECR muscles.
Result: Each M1 site activates multiple muscles. Multiple M1 sites activate the same muscle.
Conclusion: Each M1 site is involved in controlling several muscles.

Basis of the motor map

M1 output is from layer 5 pyramidal cells with axons that descend to spinal cord.

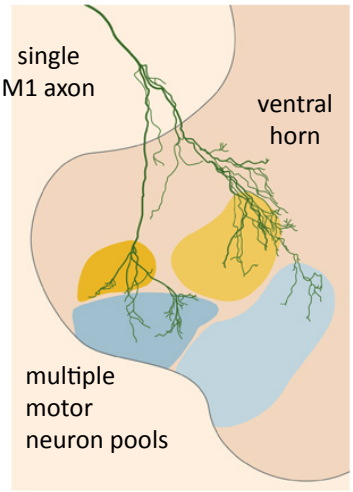
L5 neurons in M1 arm region target **arm motor neuron pools** in **cervical spinal cord**. L5 neurons in leg region target **leg motor neuron pools** in **lumbar cord**.



Basis of the motor map

Individual M1 neurons branch to synapse in **multiple pools** innervating several synergistic extensor muscles or flexor muscles.

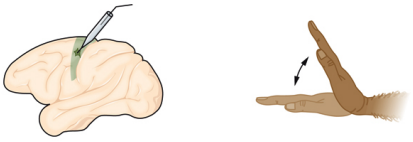
Thus each M1 neuron directly controls a group of extensor or flexor muscles.



Other pathways (rubrospinal, reticulospinal) synapse on local spinal interneurons, which control larger muscle groups for coarser control.

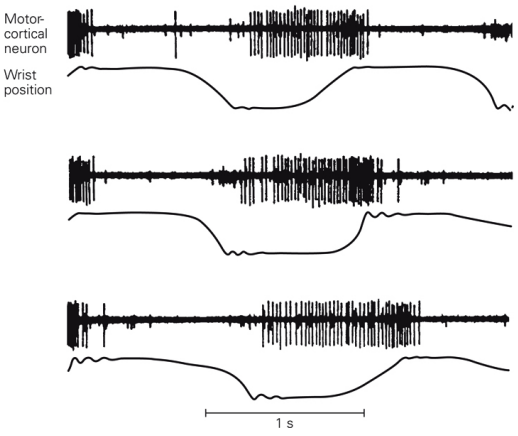
Physiology of M1 neurons during movement

Ed Evarts, NIH, 1950s-1960s. M1 recordings in awake, behaving primates.



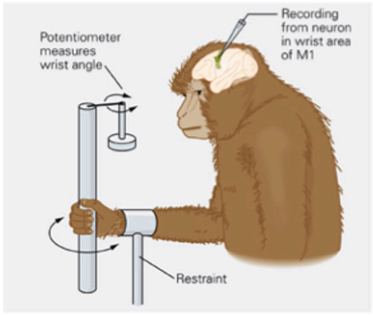
This M1 pyramidal tract neuron fires just before wrist flexion.

Other M1 neurons fire before wrist extension.

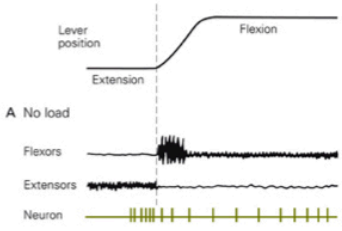


Physiology of M1 neurons during movement

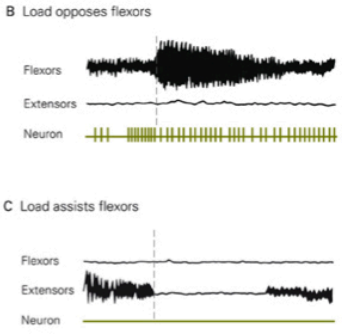
Does M1 firing command a specific limb movement in space (**kinematics**? Or does it command the force to be exerted by a muscle group (**kinetics**)?



load opposing flexors or extensors

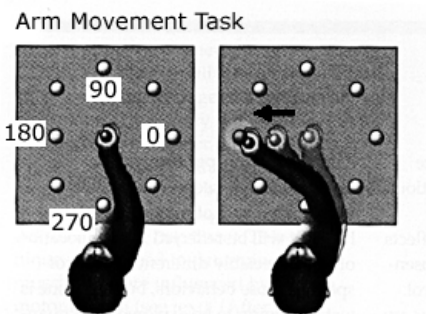


Same kinematics, different forces:

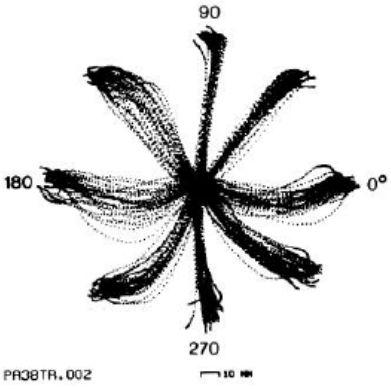


M1 coding of complex, multi-joint movement

How do M1 cells encode the direction of arm movement in a reaching task?



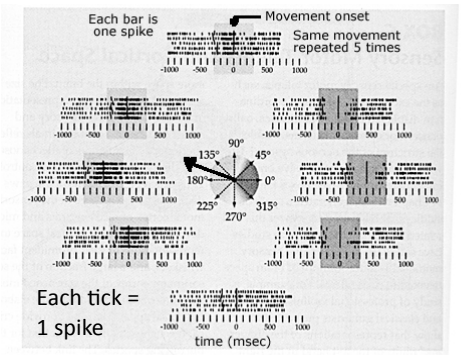
arm trajectories

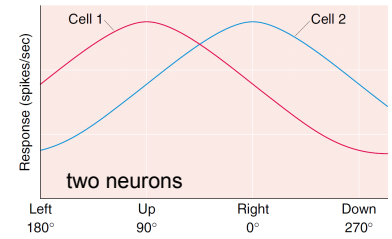


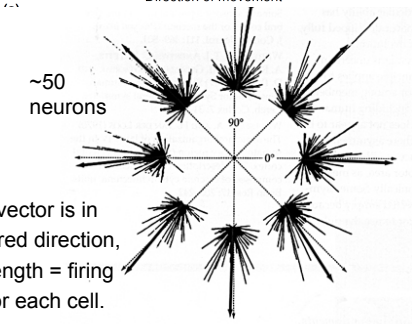
Georgopoulos et al., 1982

M1 coding of complex, multi-joint movement

Spiking of one M1 neuron during task







Single M1 neurons instruct direction poorly. But direction is well predicted by vector sum across multiple neurons.

Each vector is in preferred direction, with length = firing rate for each cell.

M1 coding of complex, multi-joint movement

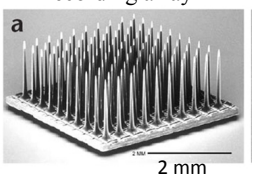
This is population coding. Population (or ensemble) coding is when information is contained in the joint activity of a large number of neurons within a population.

M1 neurons exhibit a robust population code for arm direction, but only a poor single-neuron code.

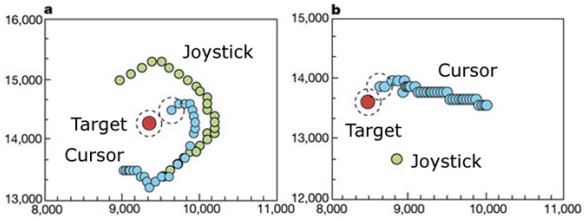
Biologically, how do you think the vector sum is implemented? i.e., how is the contribution of each M1 cell added up to determine overall arm direction?

Reading the M1 code to control neural prosthetics

Recording array



Record 7-10 M1 neurons. Monkey moves a joystick that controls a cursor on a screen.



- Spiking of M1 population
- Population decoding model
- Estimate of desired arm position
- Control cursor or robot

Monkey moves hand and cursor

Monkey moves cursor only, not hand

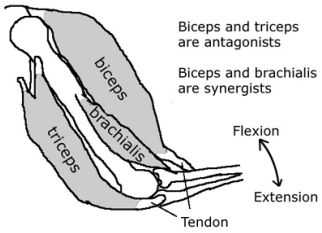
Donoghue, Fetz, Shenoy, others

Learning in the M1 map

We improve motor performance through learning, by developing more accurate motor programs.

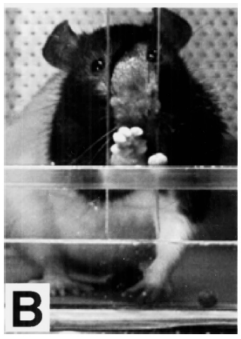
Motor programs are constantly refined and re-learned to compensate for growth, injury, exercise, and aging of the motor plant.

Motor plant

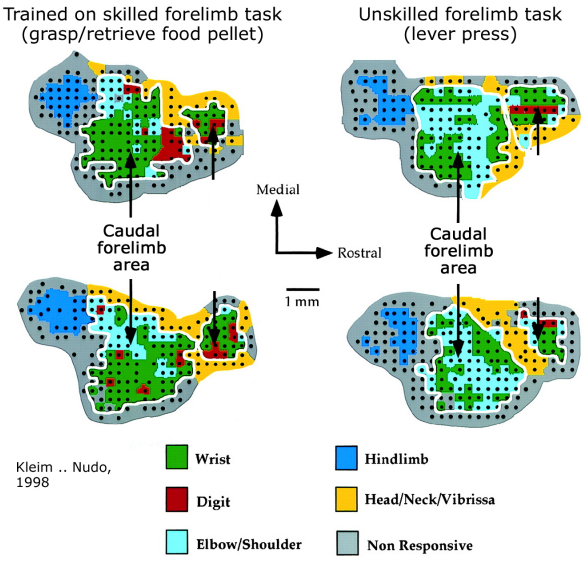


Learning in the M1 map

Learning a motor task alters the M1 map



Pellet retrieval task

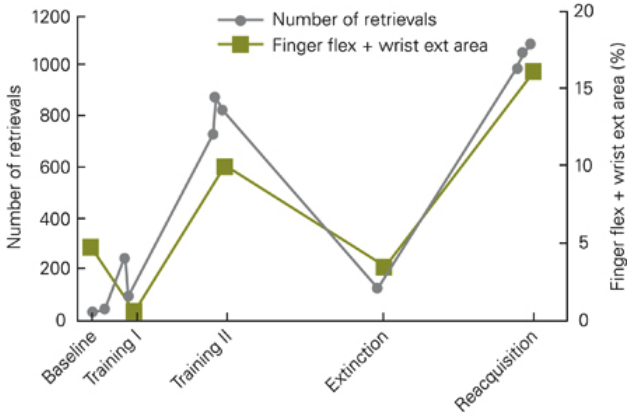


Learning in the M1 map

Map reorganization parallels behavioral motor learning

Food retrieval from a narrow well in primates: a finger/wrist task.

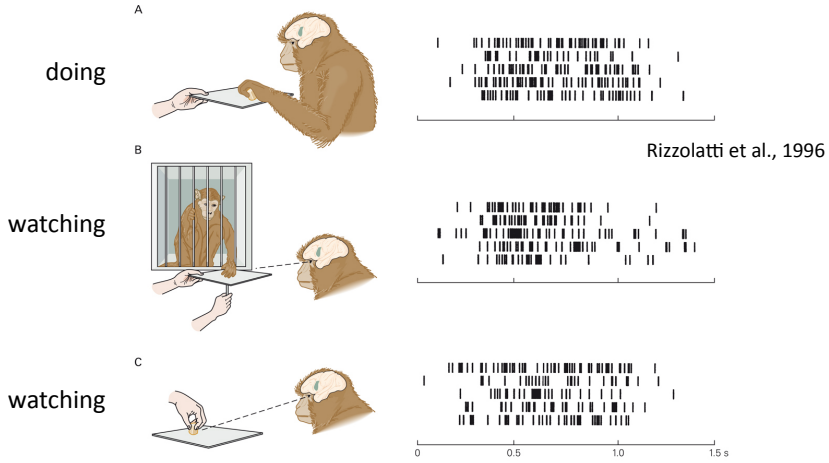
Nudo et al., 1996



Motor map changes are thought to reflect plasticity in local M1 circuits that create specialized ensembles to command skilled behaviors.

Mirror neurons for recognition of motor acts in others

Mirror neurons in ventral premotor cortex



Rizzolatti et al., 1996

Neurons that command specific movements are active when observing that specific movement in other animals.