Motor Cortex

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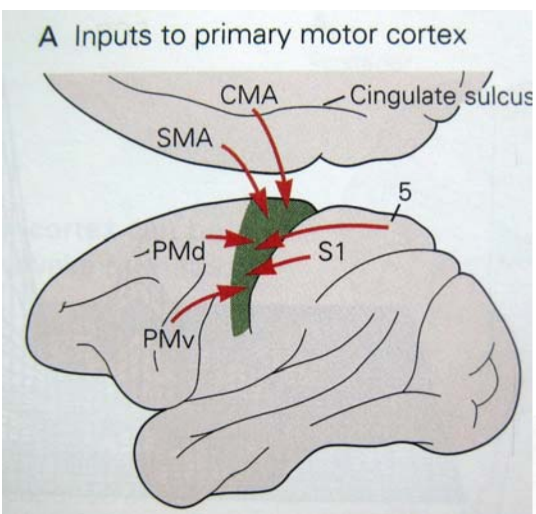
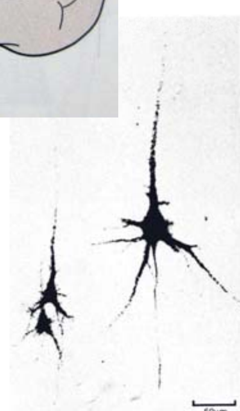
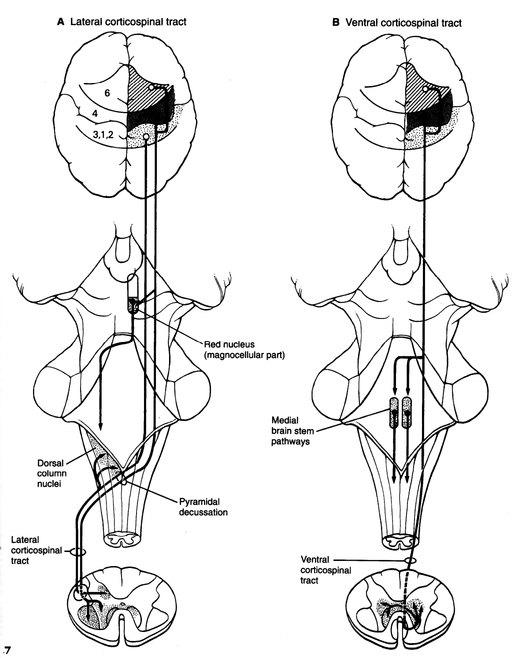
Projections to and from M1



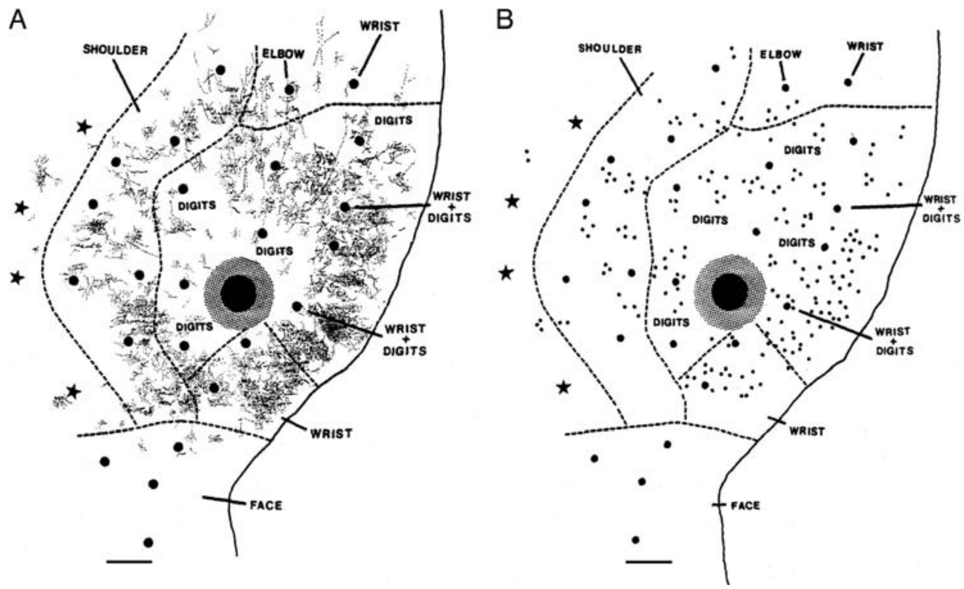




Lateral connections in M1

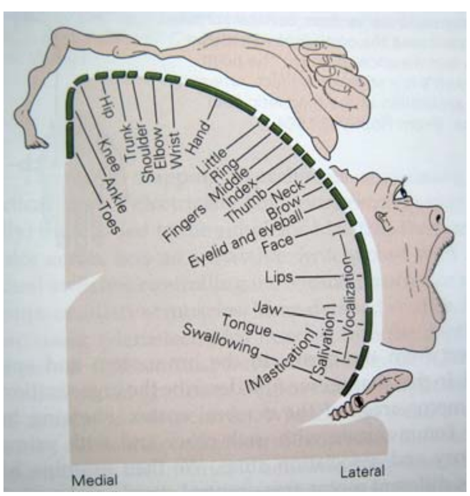
Labeling due to HRP injection

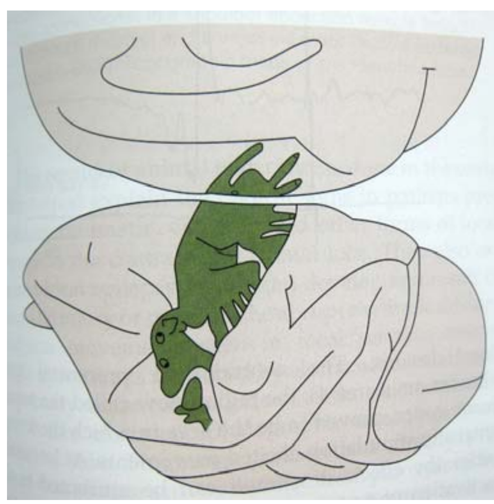
terminals neurons



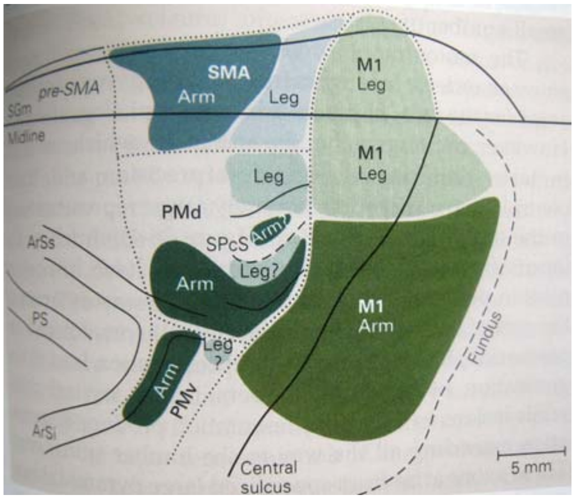
Body maps: Reasonable

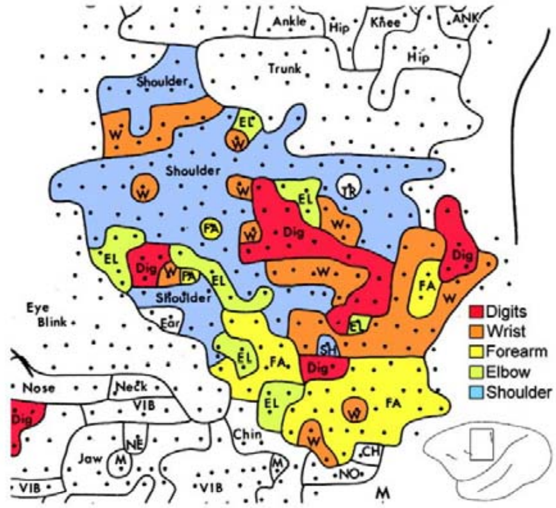
homunculus (Penfield) simiunculus (Woolsey)



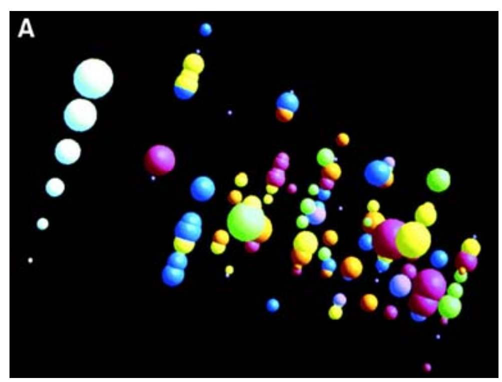


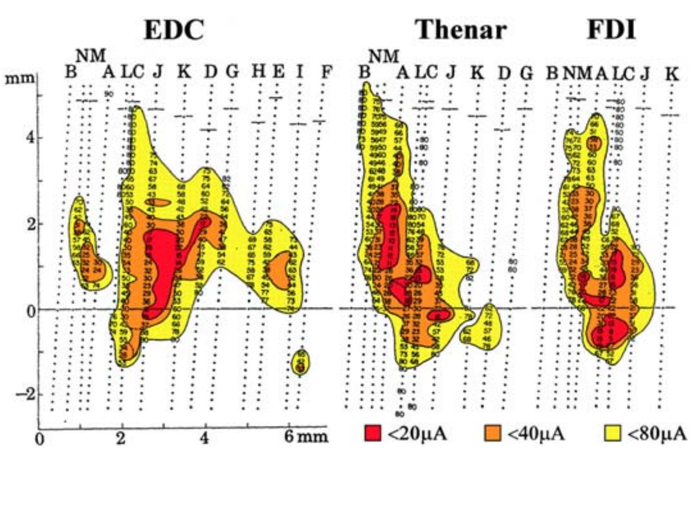
More detailed maps: Repeated representations



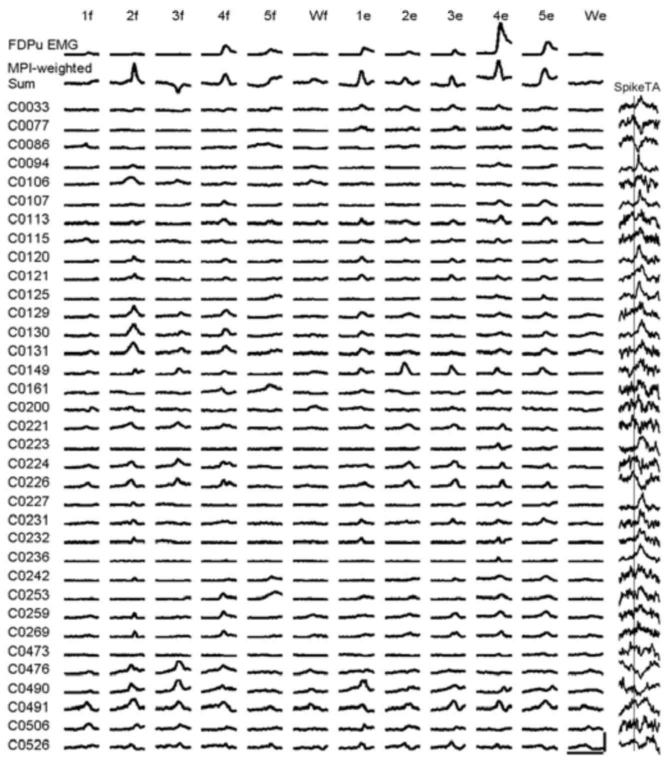


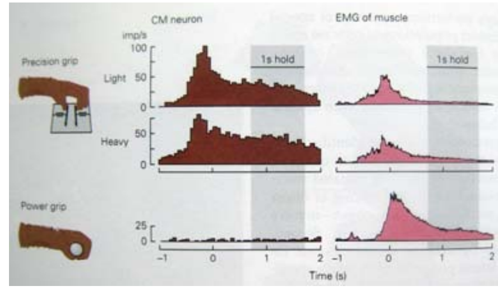
Muscle and movement “maps”: Complete mess



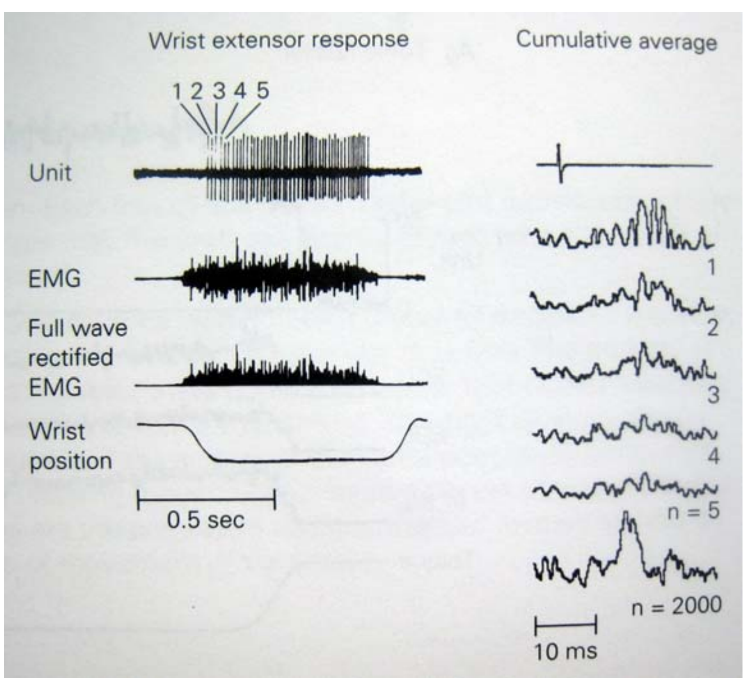


M1 activity explains EMG, but not vice versa





Spike-trigered EMG averaging



Overview of M1 physiology

Early view (Evarts)
Force (muscle) control

Later view (Georgopoulos)
Encoding of hand kinematics (velocity,position) in 2D tasks

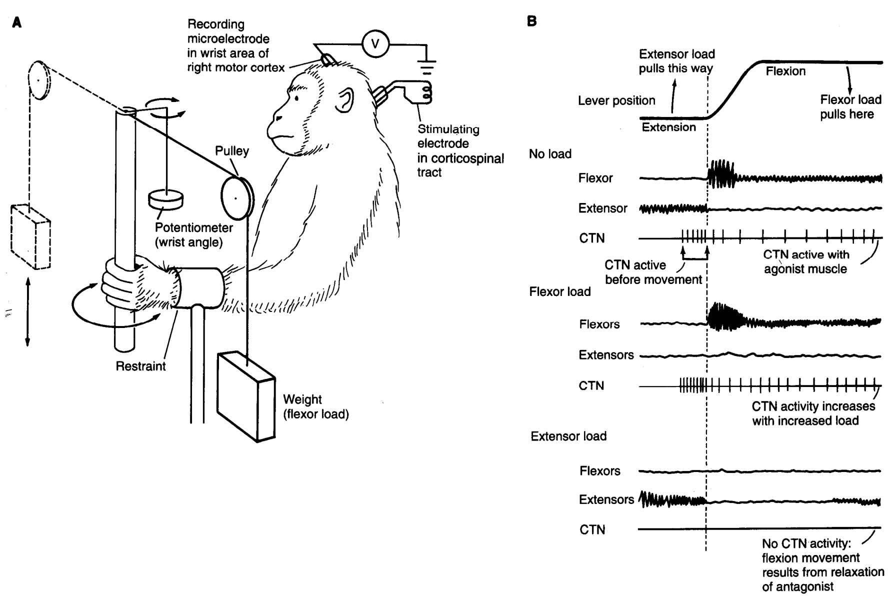
Even later (Kalaska, Scott)
M1 also encodes external loads and posture in the same 2D tasks

M1 activity also correlates with:

Position	Georgopoulos et al. 84, Kettner et al. 88
Joint configuration	Scott and Kalaska 95, Kakei et al. 99
Rate of change of force	Cheney and Fetz 80, Georgopoulos et al. 92
Acceleration	Bedingham et al. 85, Flament and Hore 88
Movement preparation	Thach 78
Target position	Alexander and Crutcher 90, Fu et al. 93
Distance to target	Fu et al. 93
Movement trajectory	Hocherman and Wise 91
Muscle coactivation	Humphrey and Reed 83
Serial order	Carpenter et al. 99
Visual target position	Georgopoulos et al. 89
Path curvature	Schwartz 94
Time from onset	Fu et al. 95

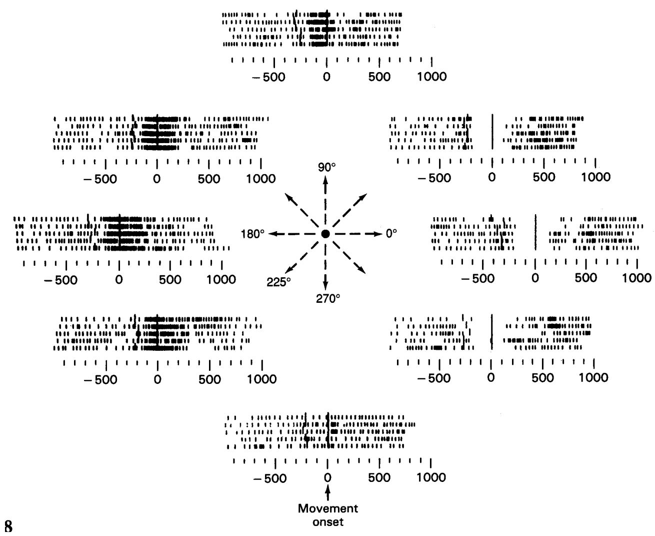
Individual neurons do bizarre things that lack a simple relation to any aspect of behavior (Churchland)

Force encoding

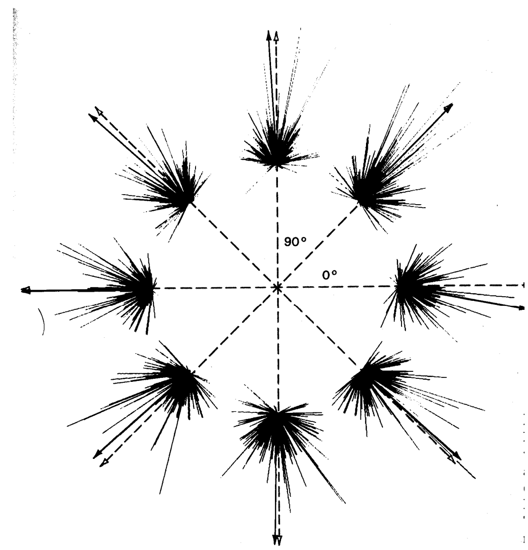


Direction encoding (cosine tuning)

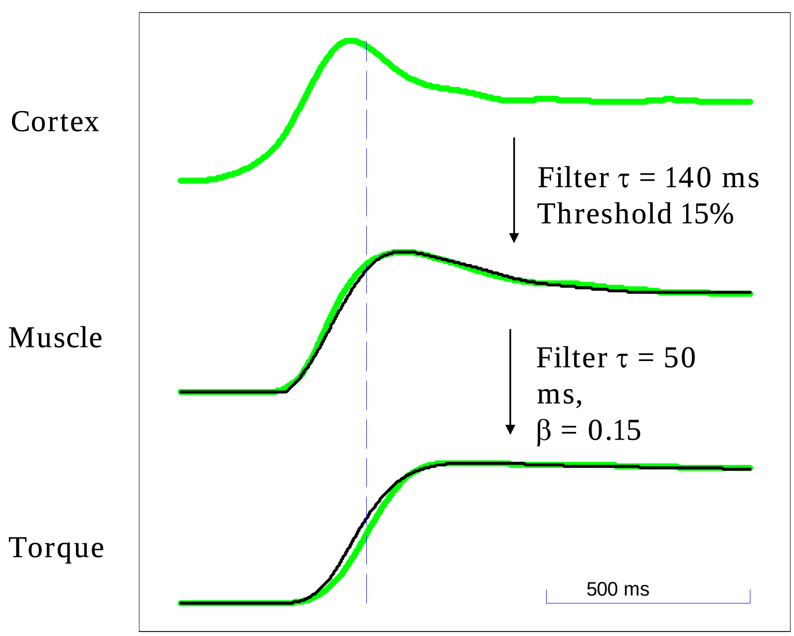
Broad directional tuning (cosine)



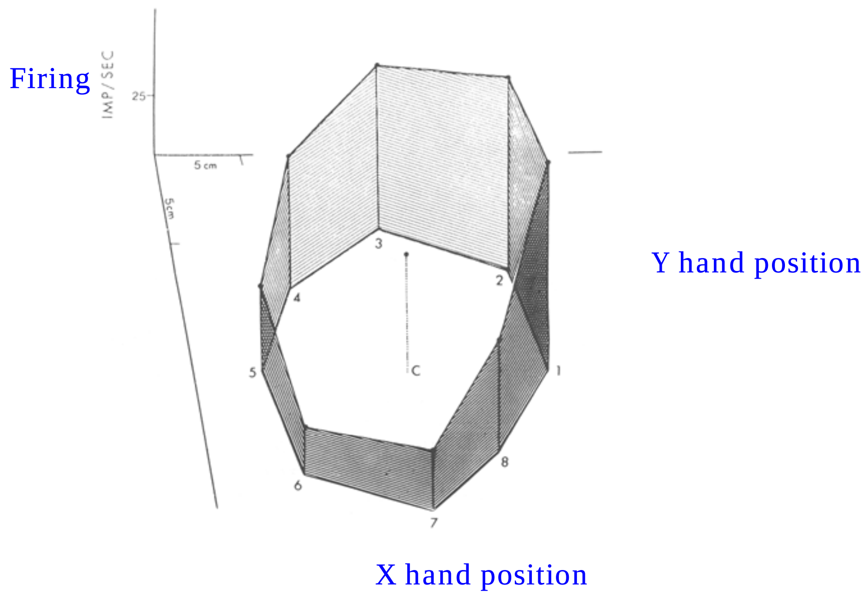
Population vectors



Phasic activity at movement/force onset

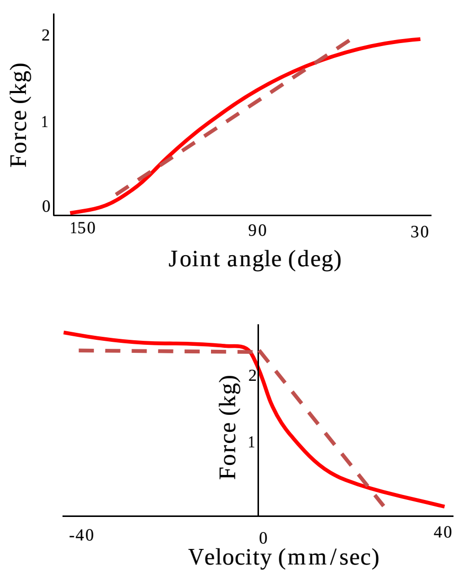


Position encoding

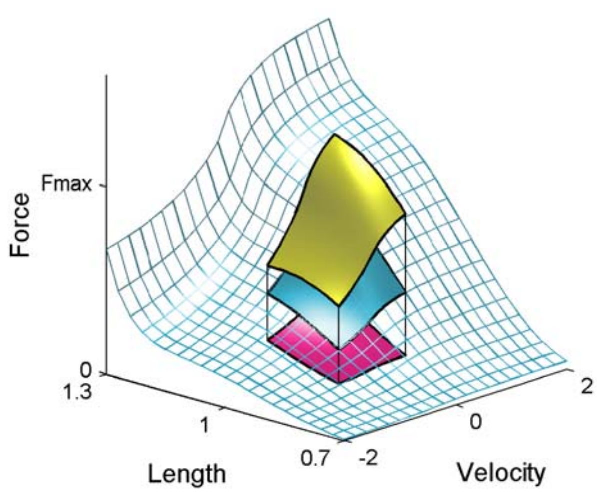


Muscle force depends on length and velocity

Joyce et al. 69



Brown et al. 99



A mechanistic model

(Todorov, Nat Neurosci 2000)

M1 cell firing: $c_j(t)$

Muscle activity: $a_i(t) = \sum_j w_{ij} c_j(t - \Delta)$

Muscle model: $f(a, x, \dot{x}) = a - kx - \lfloor b\dot{x} \rfloor$

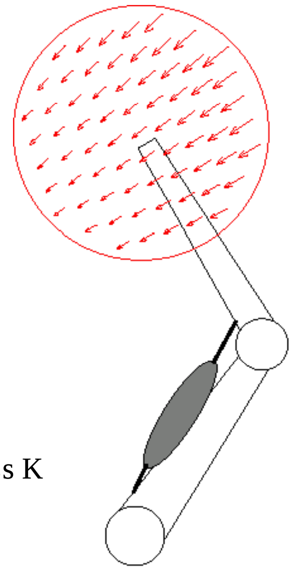
Force field: $\mathbf{f}_i(a_i, \mathbf{x}, \dot{\mathbf{x}}) = (a_i - k_i \mathbf{x} \cdot \mathbf{p}_i - b_i \lfloor \dot{\mathbf{x}} \cdot \mathbf{p}_i \rfloor)\, \mathbf{p}_i$

Net force: $PW\mathbf{c} - K\mathbf{x} - B\dot{\mathbf{x}} = M\ddot{\mathbf{x}} + \mathbf{f}_{ext}$

Arm model: asymmetric mass M, damping B, stiffness K

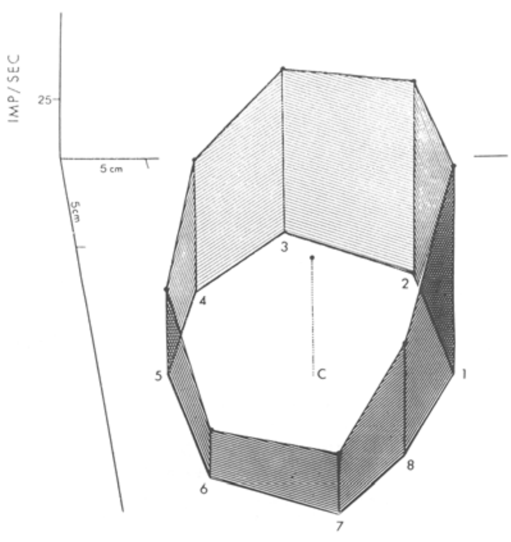
Mechanics: $PW = F_{2x2} U_{2x\text{Cells}}, M = mF, B = bF, K = kF$

Parameters: $m = 1\,\text{Ns}^2/\text{m}, b = 10\,\text{Ns/m}, k = 50\,\text{N/m}, F_{asp} = 2:1$

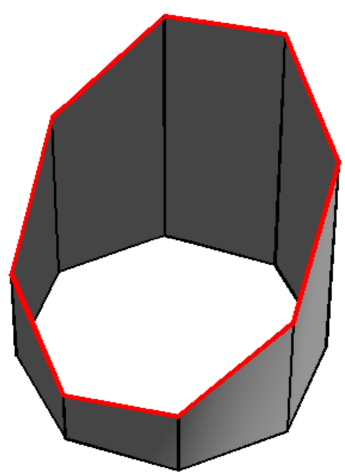


Position encoding

Georgopoulos and Massey 85

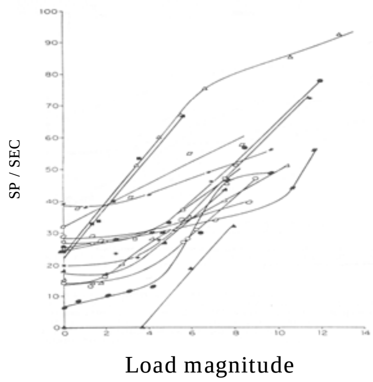


Model

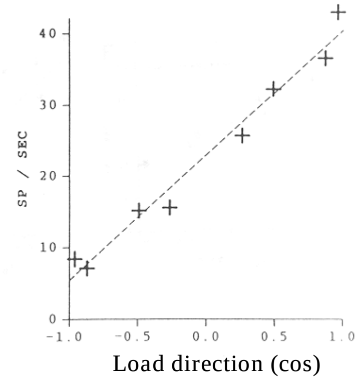


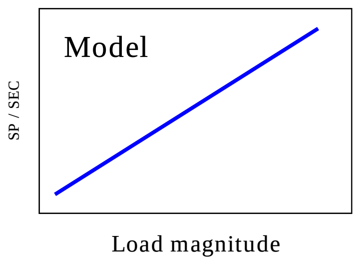
Force encoding

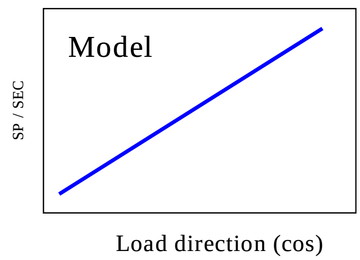
Cheney and Fetz 80



Kalaska et al. 89

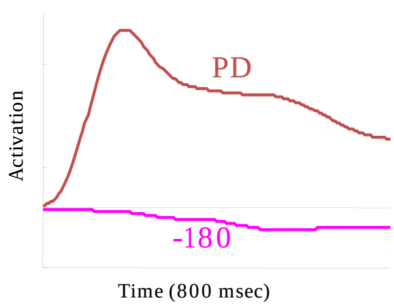




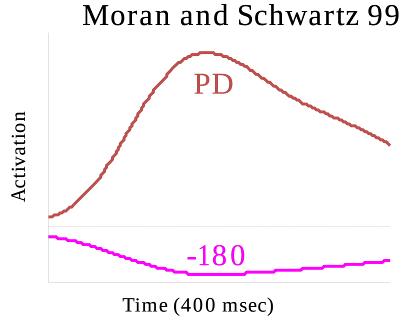


Velocity encoding

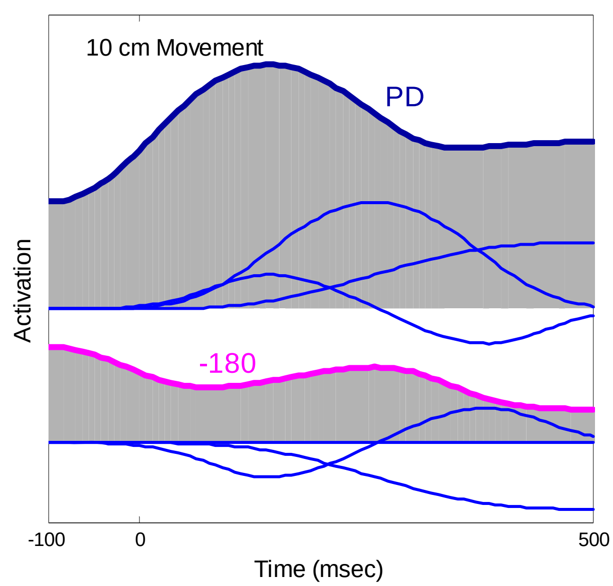
Crammond and Kalaska 96



Moran and Schwartz 99

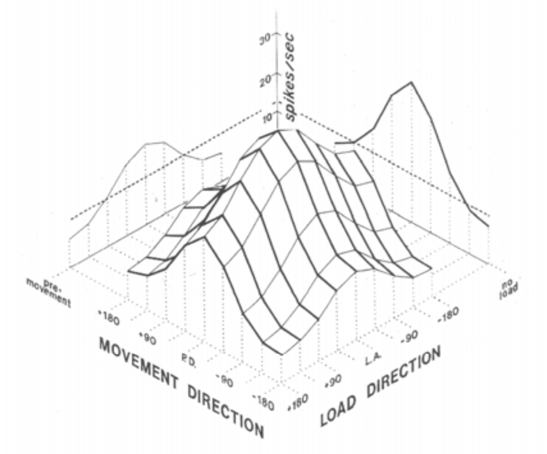


Model

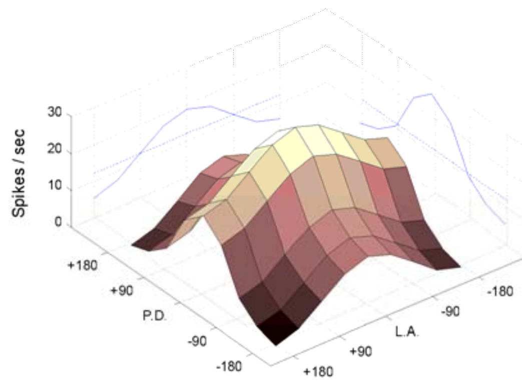


Simultaneous velocity and force encoding

Kalaska et al. 89



Model

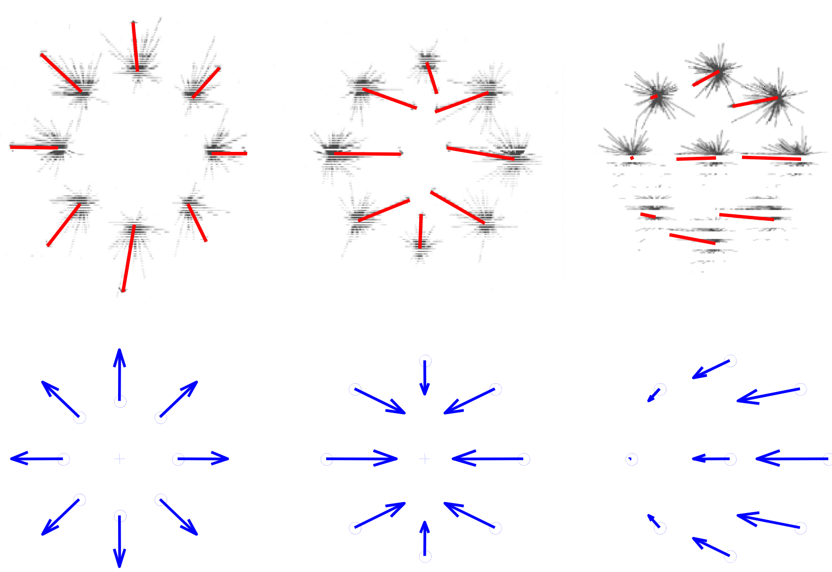


Population vector distortions

Movement | Load | Movement+Load

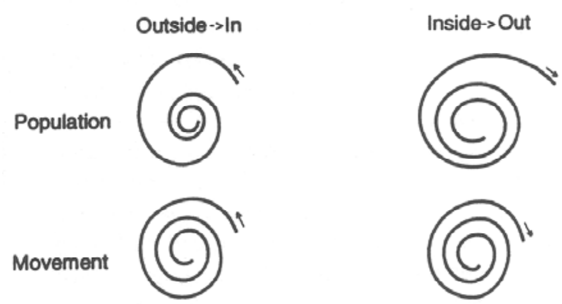
Kalaska et al. 89

Model

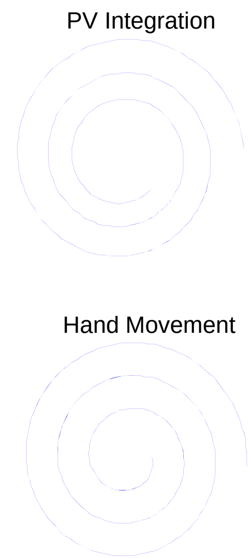


Path reconstruction via PV integration

Schwartz 94

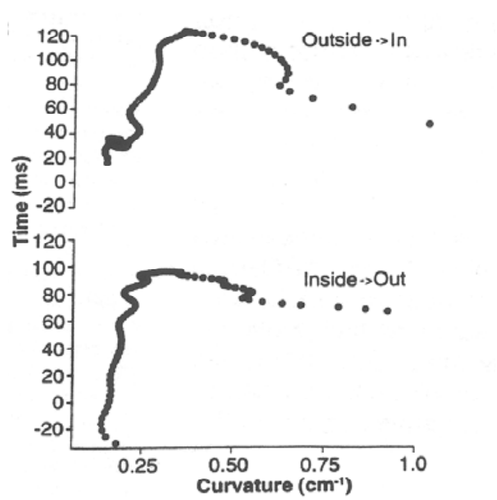


Model

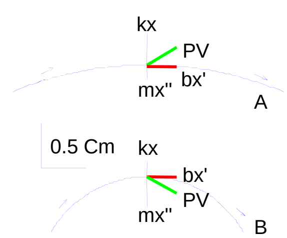


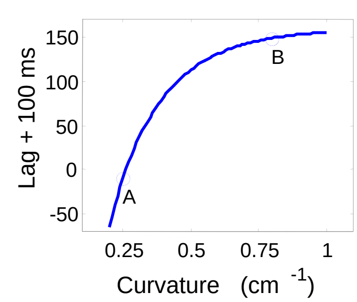
Apparent changes in M1-movement latency

Schwartz 94



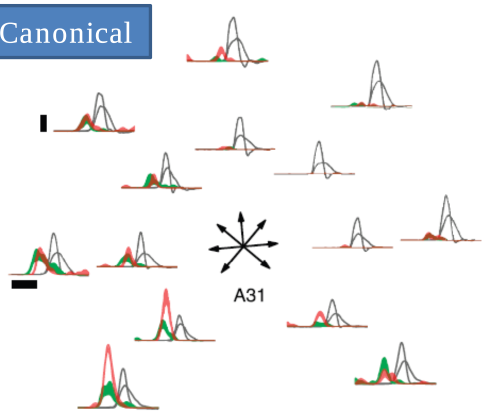
Model



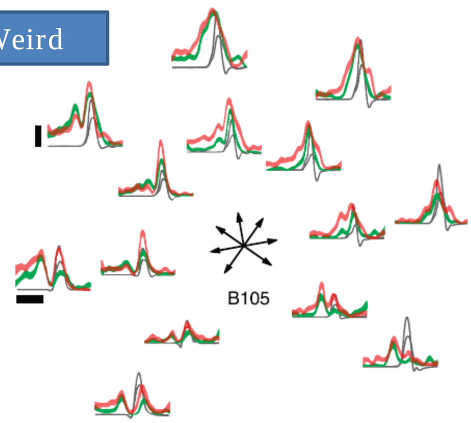


Complexity of M1 activity

Canonical

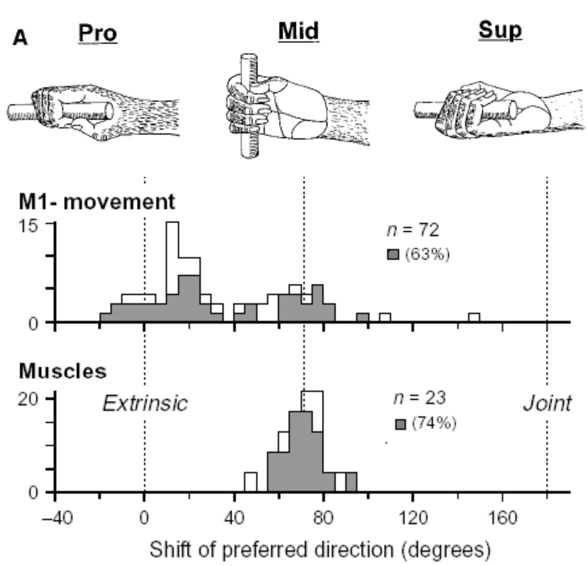


Weird

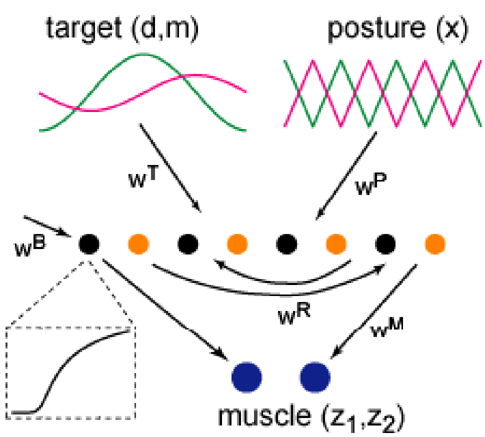


Churchland and Shenoy 2007

Extrinsic and intrinsic signals in M1



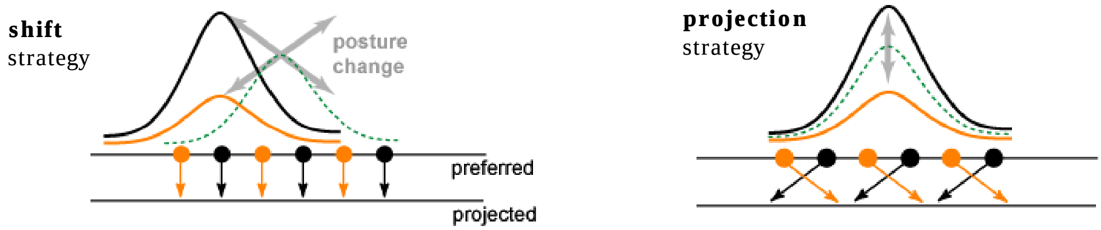
Kakei, Hoffman and Strick (1999)



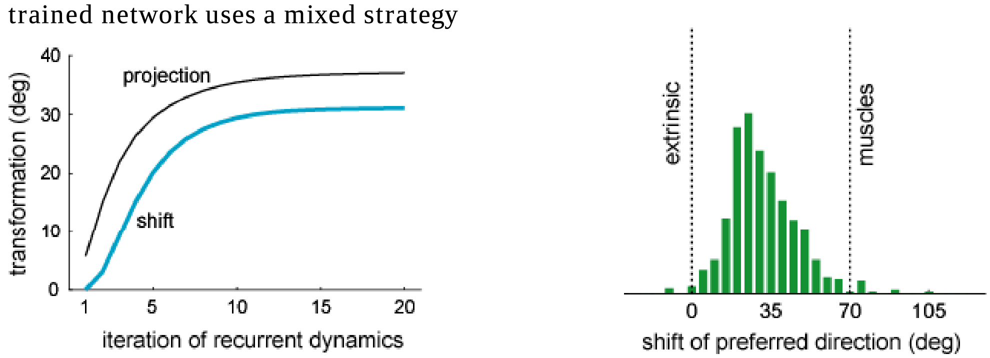
Poisson-like noise added to:
- input signals
- recurrent signals
- output signals

Model

candidate "pure" strategies for postural compensation

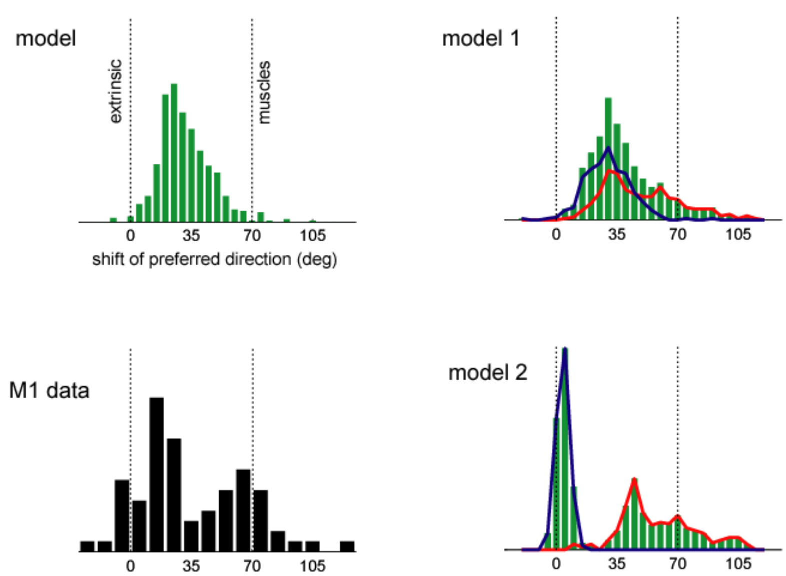


the trained network uses a mixed strategy



the key determinant of what strategy is optimal turns out to be **noise**:
when any 2 out of the 3 noise terms are removed the preferred directions no longer shift

Bi-modal distributions



model: all neurons are interconnected and project to the muscles
model 1: half of the neurons ("interneurons") do not project to the muscles
model 2: the output neurons do not project to the interneurons

Gaziano's view

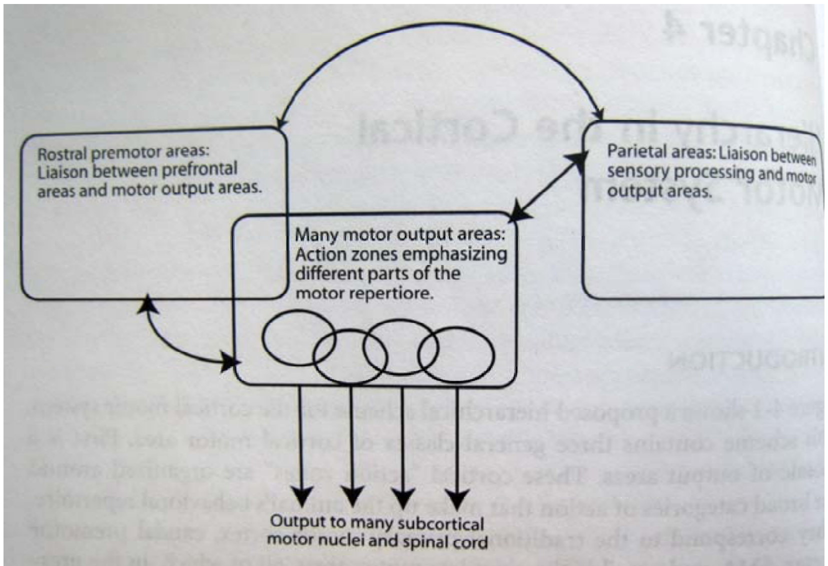
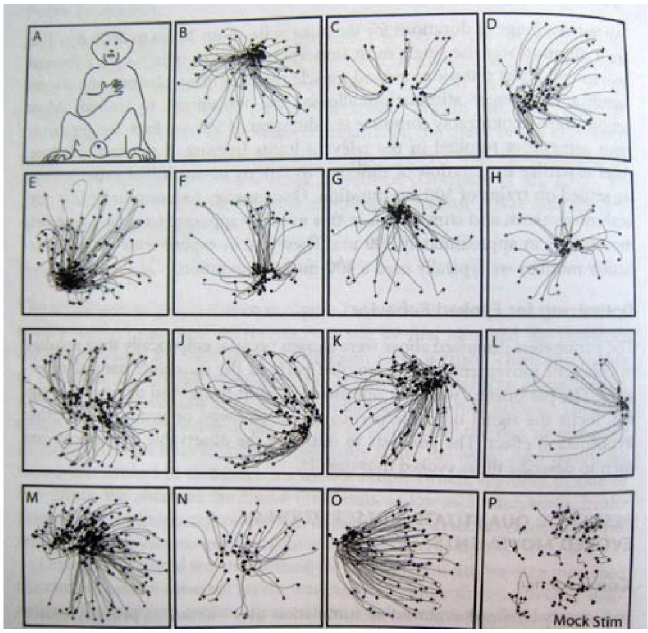
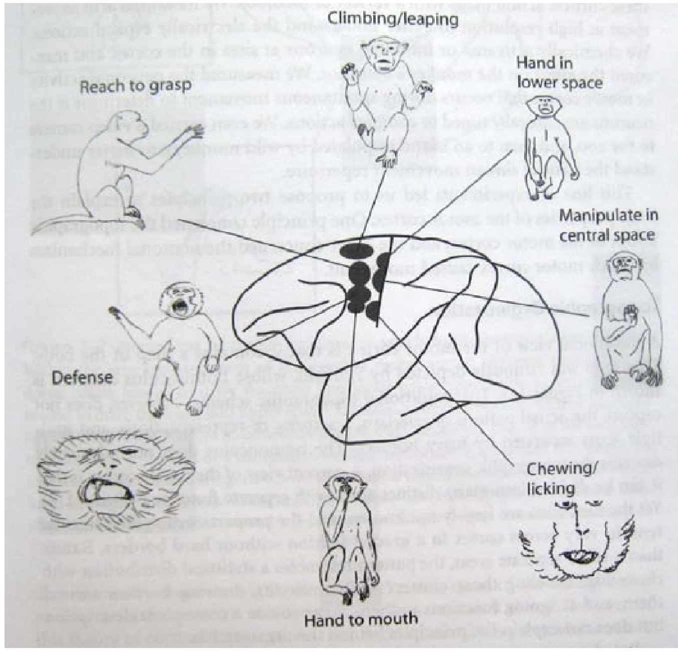


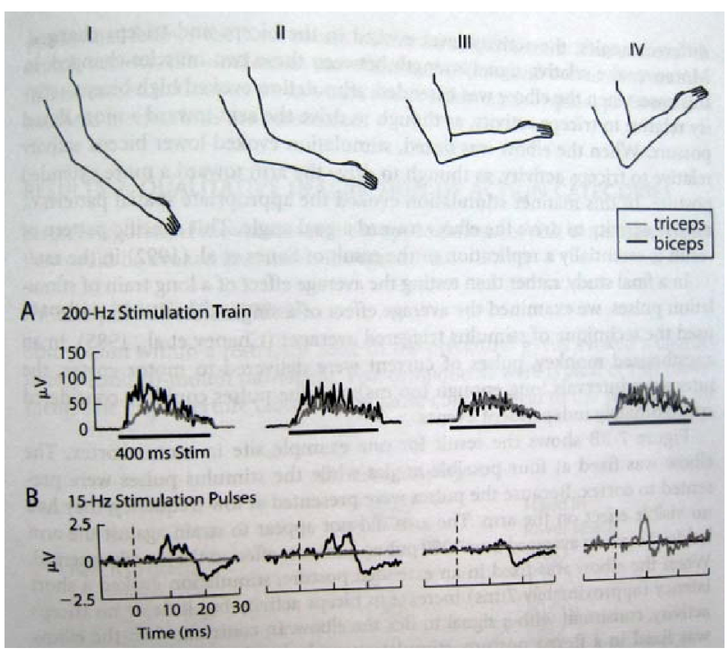
Figure 4-1 Proposed hierarchy of the cortical motor system.

Effects of macro-stimulation

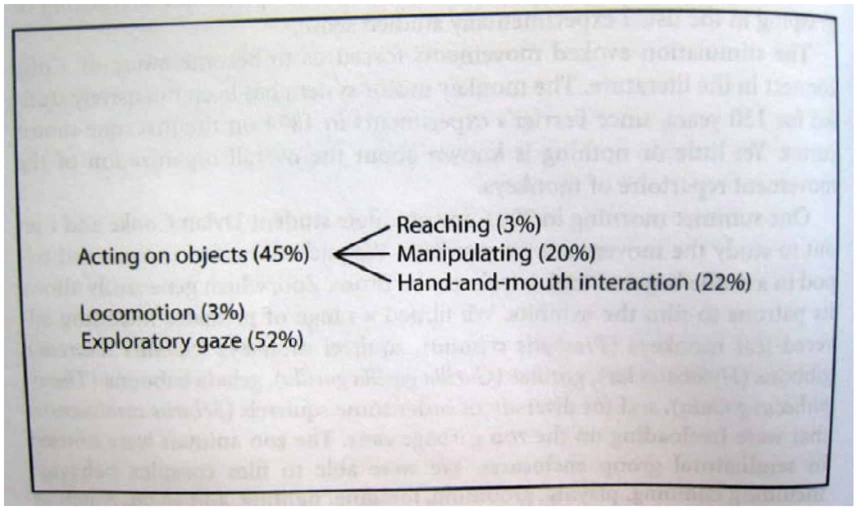


Map of the behavioral repertoire



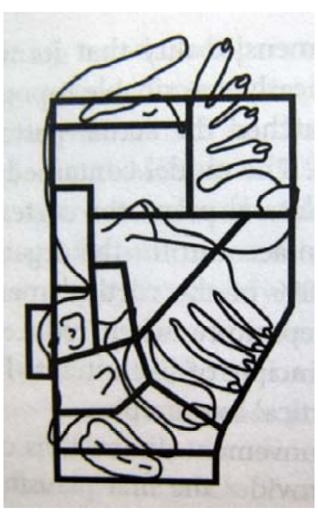


What monkeys do in the wild



Modeling of the topographic map

Initialization of the
Kohonen map model



Results