Motor Cortex

Emo Todorov

Applied Mathematics
Computer Science and Engineering

University of Washington

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:

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<td>Position</td>
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<td>Path curvature</td>
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<td>Time from onset</td>
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Individual neurons do bizarre things that lack a simple relation to any aspect of behavior (Churchland)

Force encoding

A recording microelectrode in motor cortex
B stimulating electrode in corticospinal tract

Recording microelectrode in right motor cortex
Stimulating electrode in corticospinal tract

Lever position
No load
Flexor
Extensor
CTN
Flexor load
Extensor load
CTN active
CTN active before movement
CTN active with increased load
Extensor load
Flexor load
Flexor
Extensor
CTN
No CTN activity: flexion movement results from relaxation of antagonists
Direction encoding (cosine tuning)

Broad directional tuning (cosine)

Population vectors

Cortex

Filter $\tau = 140$ ms
Threshold 15%

Muscle

Filter $\tau = 50$ ms,
$\beta = 0.15$

Torque

500 ms
Position encoding

[Graph showing firing pattern with X and Y hand positions]

Muscle force depends on length and velocity

Joyce et al. 69

Brown et al. 99

[Graph showing force vs joint angle and force vs velocity plots]
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: \( f(a, x, \dot{x}) = \dot{a} - k x - \lfloor b \dot{x} \rfloor \)

Force field: \( f_i (a_i, x, \dot{x}) = (a_i - k_i x \cdot p_i - b_i \lfloor x \cdot p_i \rfloor) \cdot p_i \)

Net force: \( PWc - Kx - B\dot{x} = M\ddot{x} + f_{ext} \)

Arm model: asymmetric mass \( M \), damping \( B \), stiffness \( K \)

Mechanics: \( PW = F_{2 \times 2} U_{2 \times \text{Cells}}, M = mF, B = bF, K = kF \)

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

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Position encoding

Georgopoulos and Massey 85

Model
Force encoding

Cheney and Fetz 80

Kalaska et al. 89

Model

SP / SEC

Load magnitude

SP / SEC

Load direction (cos)

Velocity encoding

Crammond and Kalaska 96

Moran and Schwartz 99

Model

10 cm Movement

Activation

Time (800 msec)

100 0 500

Time (msec)

Activation

-180

-180

-180

Time (400 msec)
Simultaneous velocity and force encoding

Kalaska et al. 89

Model

Population vector distortions

Kalaska et al. 89

Movement        Load        Movement+Load

Model
Path reconstruction via PV integration

Schwartz 94

Outside → In
Inside → Out

Population

Movement

Model

PV Integration

Hand Movement

Apparent changes in M1-movement latency

Schwartz 94

Outside → In
Inside → Out

Model

PV

Curvature (cm⁻¹)

Lag + 100 ms

Curvature (cm⁻¹)
Complexity of M1 activity

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
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
What monkeys do in the wild

- Acting on objects (45%)
- Reaching (3%)
- Manipulating (20%)
- Locomotion (3%)
- Hand-and-mouth interaction (22%)
- Exploratory gaze (52%)

Modeling of the topographic map

Initialization of the Kohonen map model

Results