BBCI Workshop 2009

Advances in Neurotechnology

Berlin
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BRAIN-MACHINE INTERFACES BASED ON NEURONAL ENSEMBLE RECORDINGS

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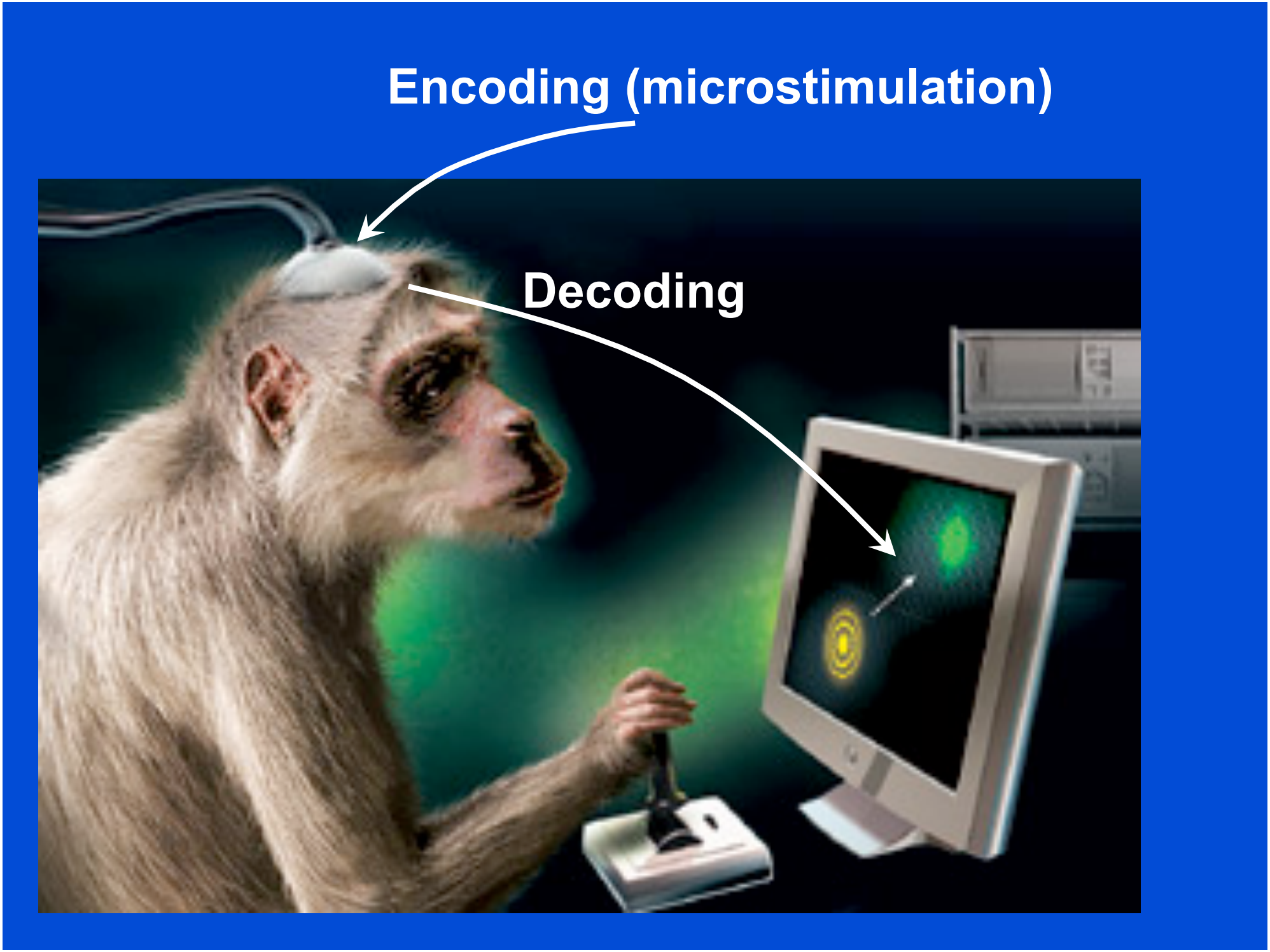
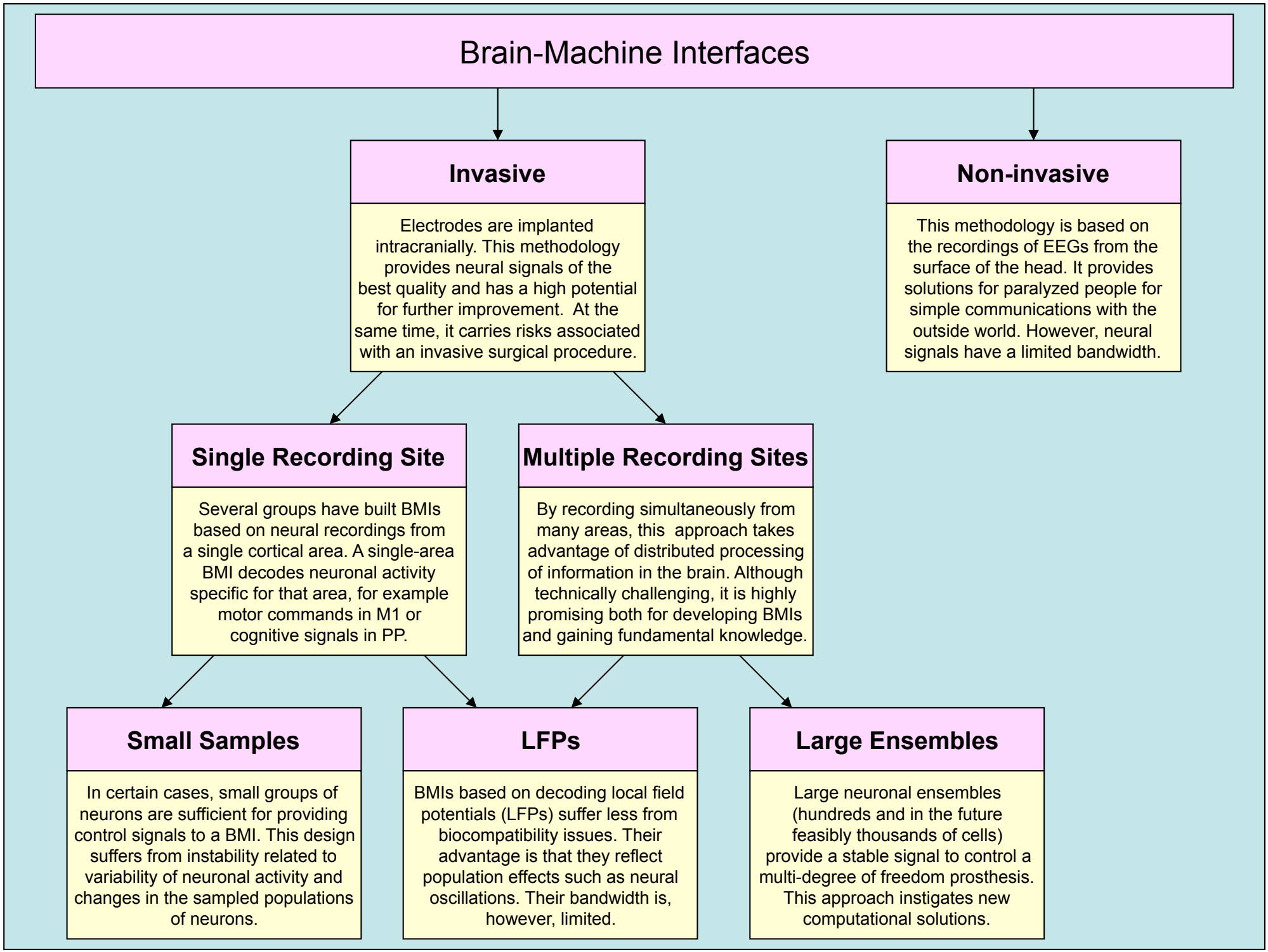
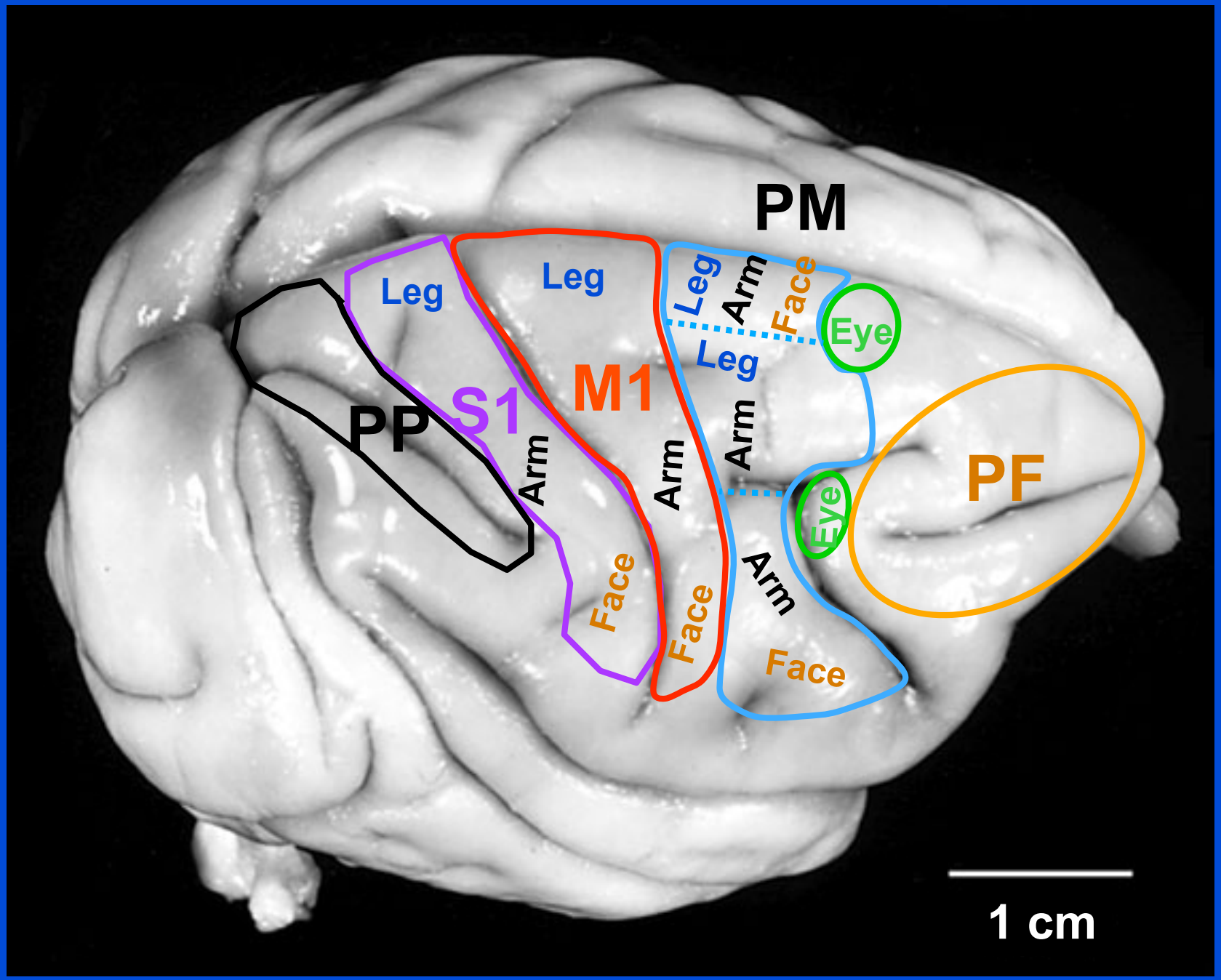
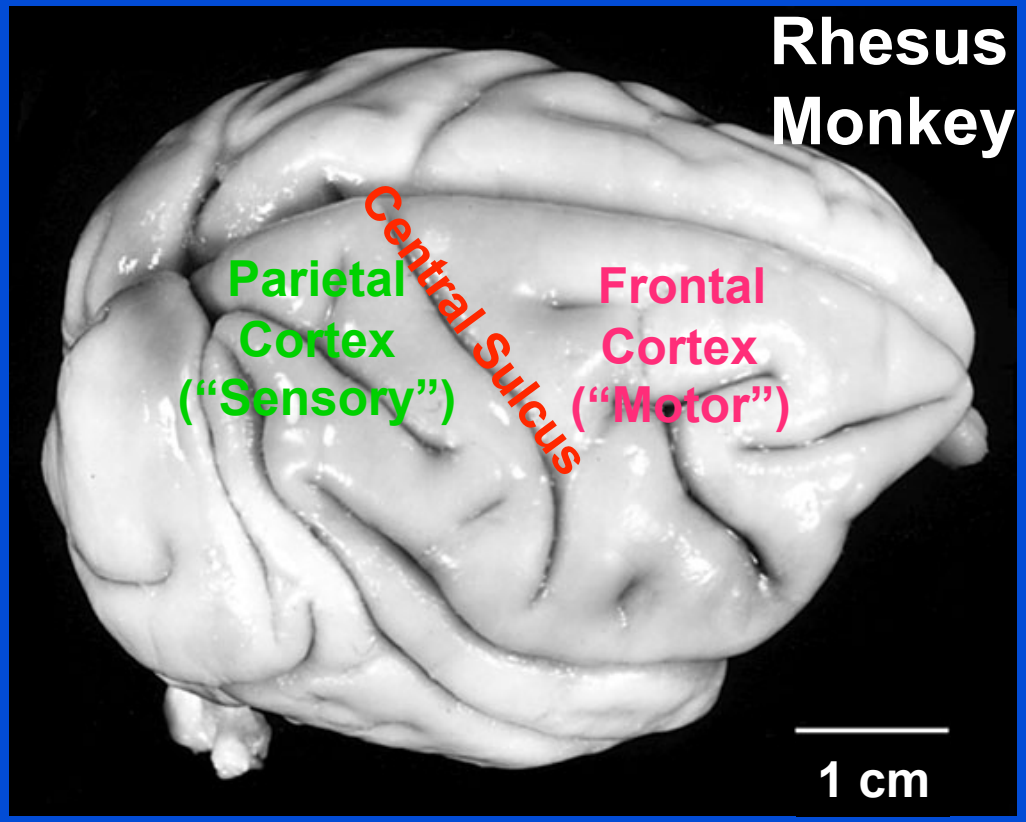

Encoding (microstimulation)
Decoding

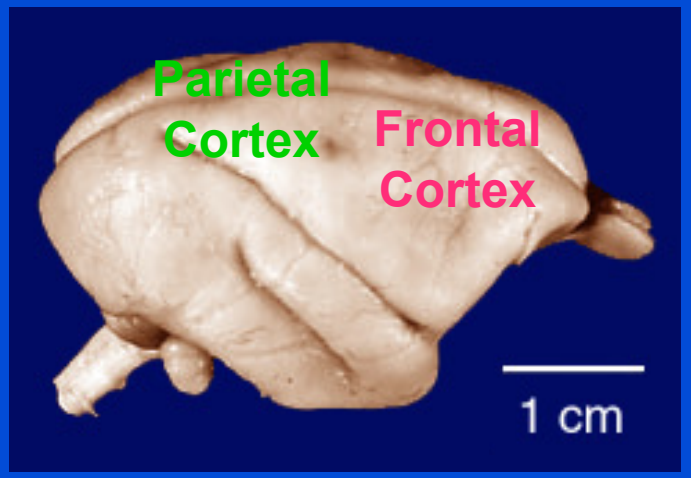

Brain-Machine Interfaces
Invasive
Electrodes are implanted intracranially. This methodology provides neural signals of the best quality and has a high potential for further improvement. At the same time, it carries risks associated with an invasive surgical procedure.
Non-invasive
This methodology is based on the recordings of EEGs from the surface of the head. It provides solutions for paralyzed people for simple communications with the outside world. However, neural signals have a limited bandwidth.
Single Recording Site
Several groups have built BMIs based on neural recordings from a single cortical area. A single-area BMI decodes neuronal activity specific for that area, for example motor commands in M1 or cognitive signals in PP.
Multiple Recording Sites
By recording simultaneously from many areas, this approach takes advantage of distributed processing of information in the brain. Although technically challenging, it is highly promising both for developing BMIs and gaining fundamental knowledge.
Small Samples
In certain cases, small groups of neurons are sufficient for providing control signals to a BMI. This design suffers from instability related to variability of neuronal activity and changes in the sampled populations of neurons.
LFPs
BMIs based on decoding local field potentials (LFPs) suffer less from biocompatibility issues. Their advantage is that they reflect population effects such as neural oscillations. Their bandwidth is, however, limited.
Large Ensembles
Large neuronal ensembles (hundreds and in the future feasibly thousands of cells) provide a stable signal to control a multi-degree of freedom prosthesis. This approach instigates new computational solutions.

Macaque Monkey Brain

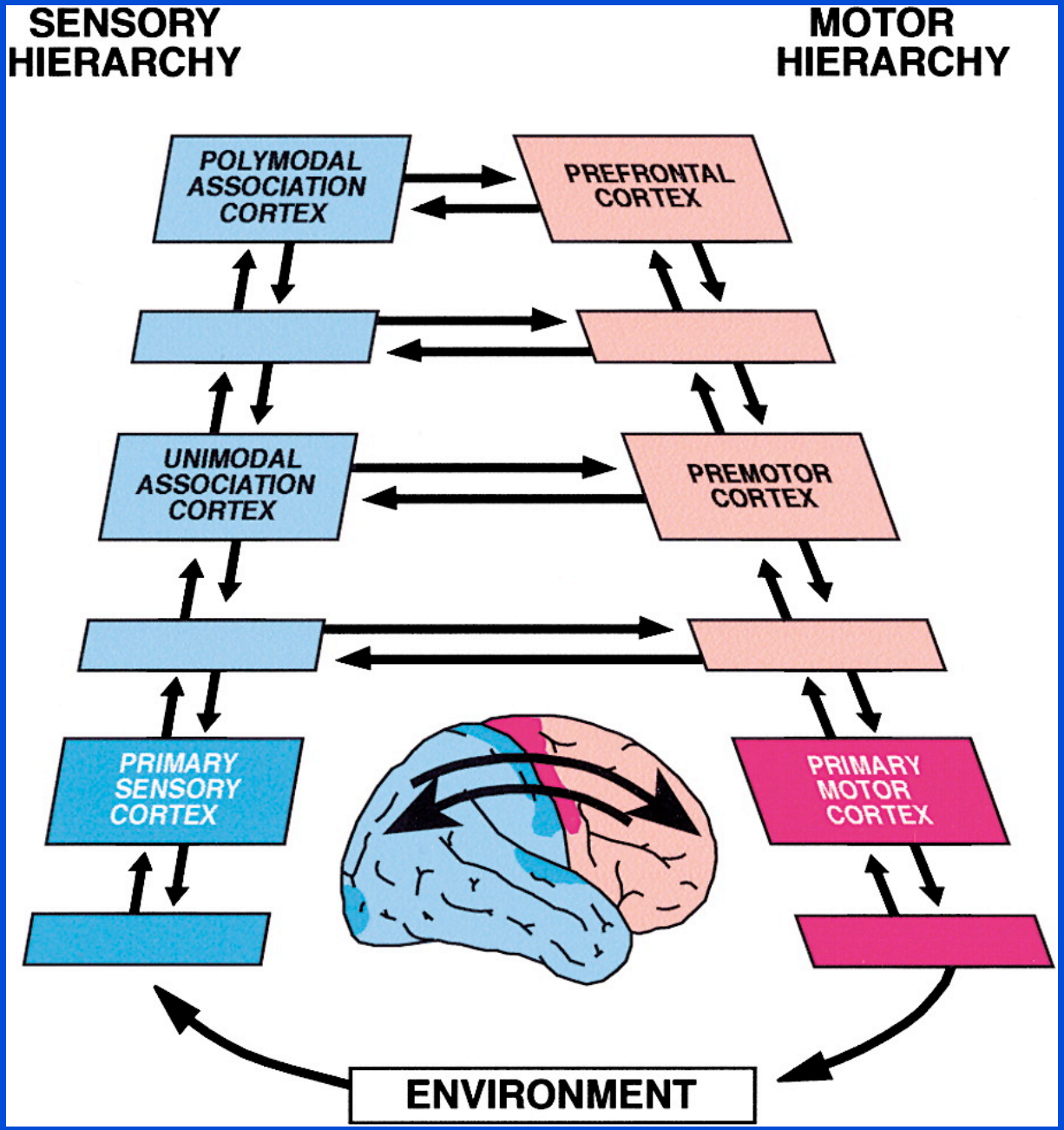



Rhesus Monkey
Central Sulcus
Parietal Cortex ("Sensory")
Frontal Cortex ("Motor")
1 cm

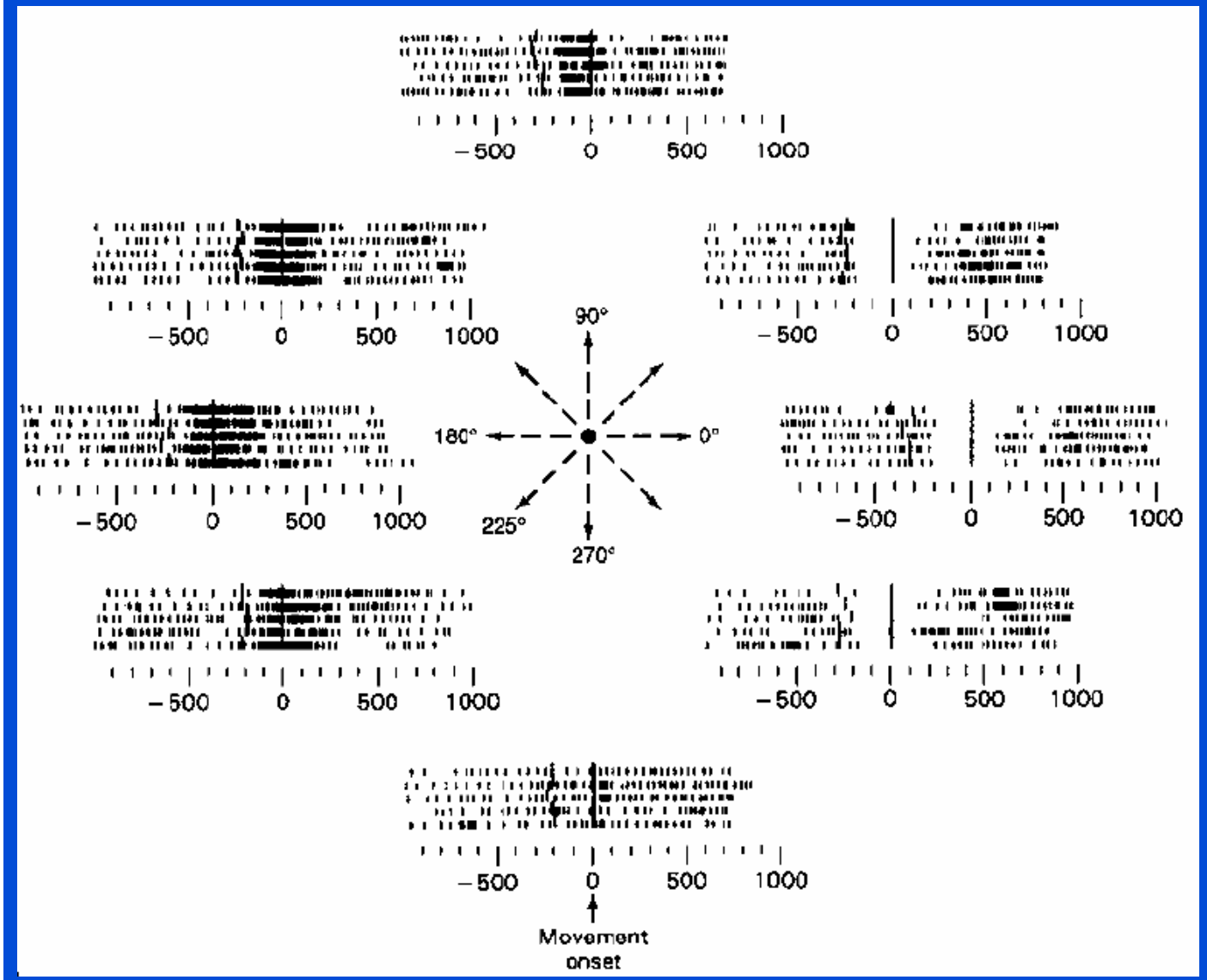
Owl Monkey


Parietal Cortex
Frontal Cortex
1 cm

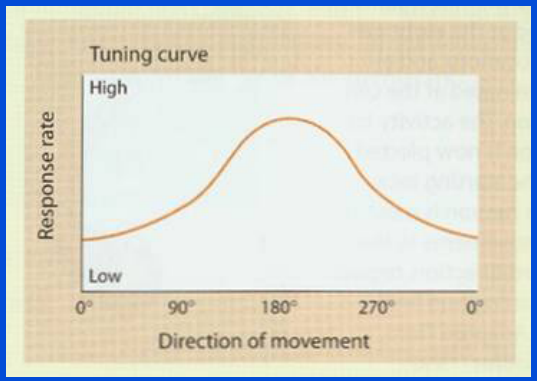
Cortical Hierarchy according to Fuster (2001)

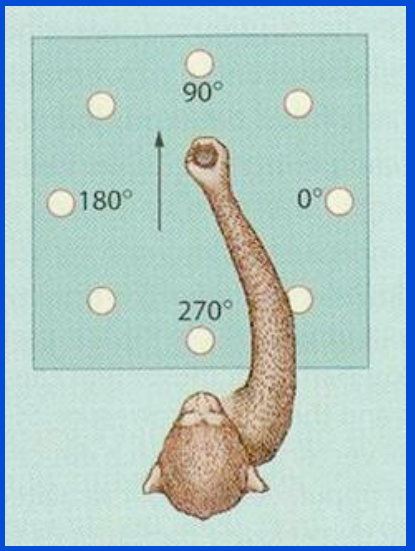


Cortical Neurons Are Directionally Tuned



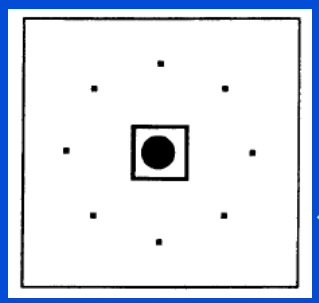
$$Rate = A + B\cos(\theta - \theta_0)$$



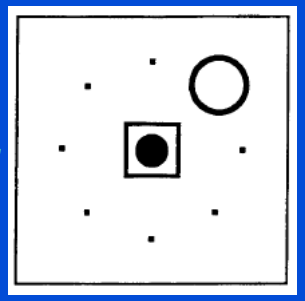


Georgopoulos et al. (80s)

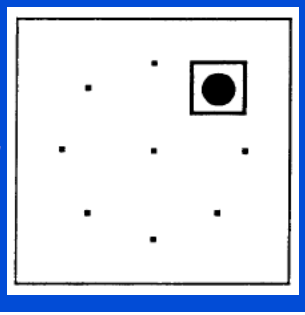
Frontal Cortex Neurons Modulate Firing During Movement Preparation and Execution

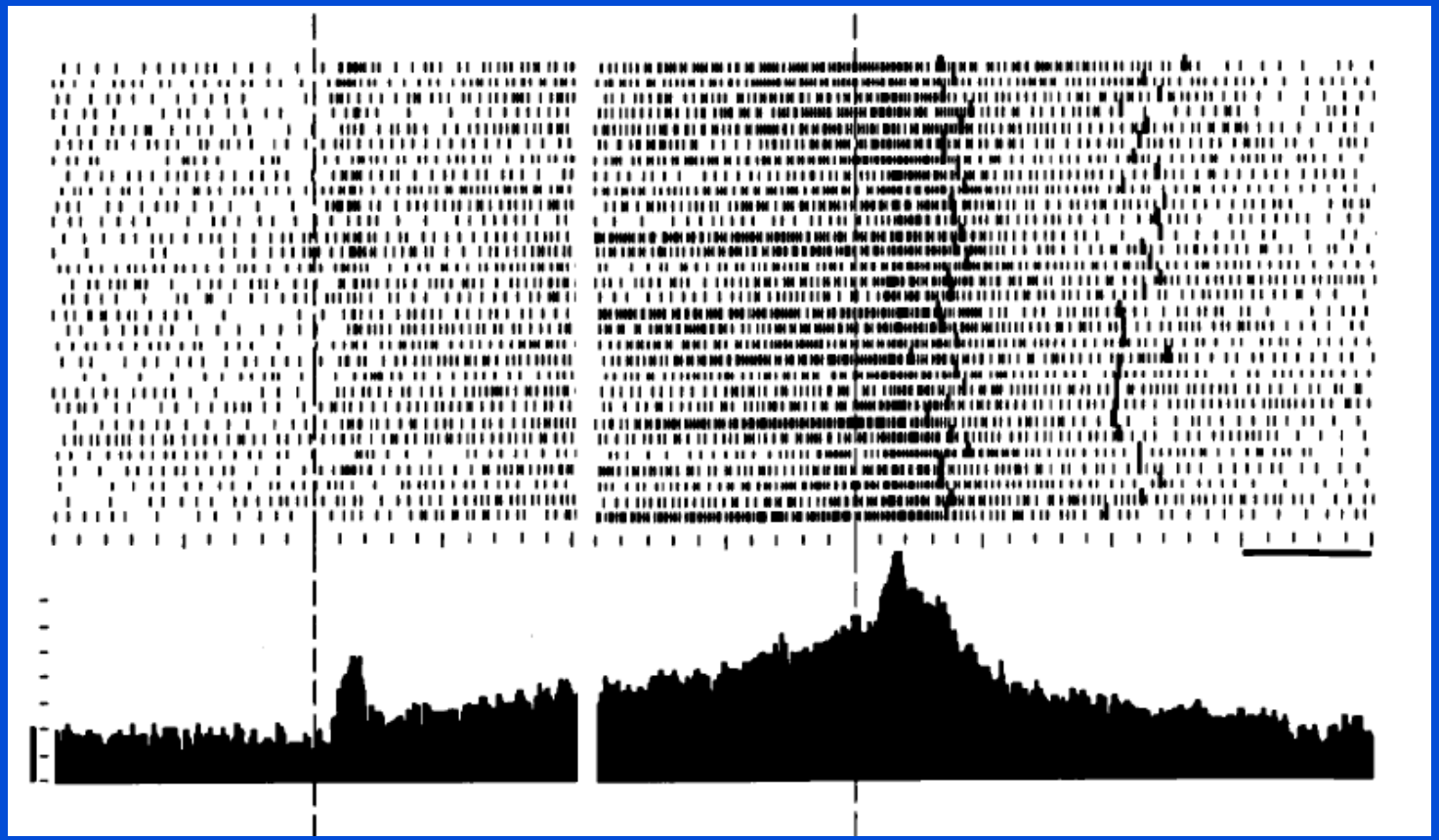


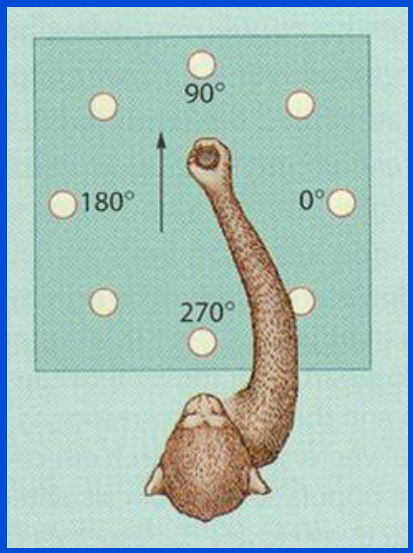
Instruction



Go



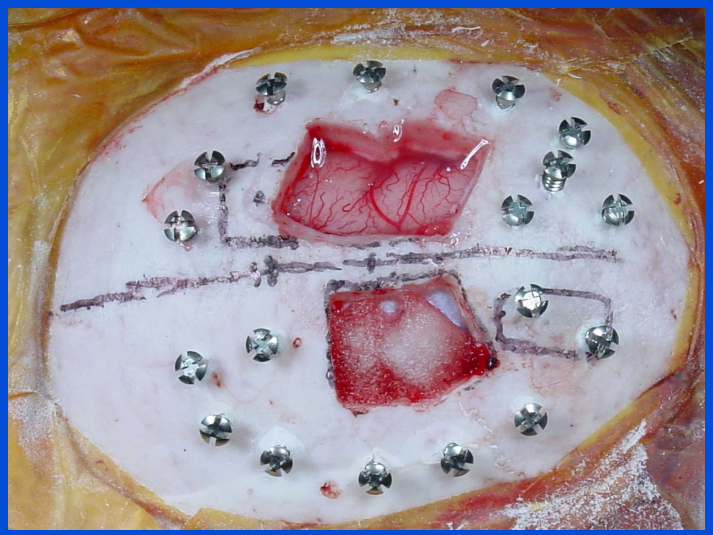




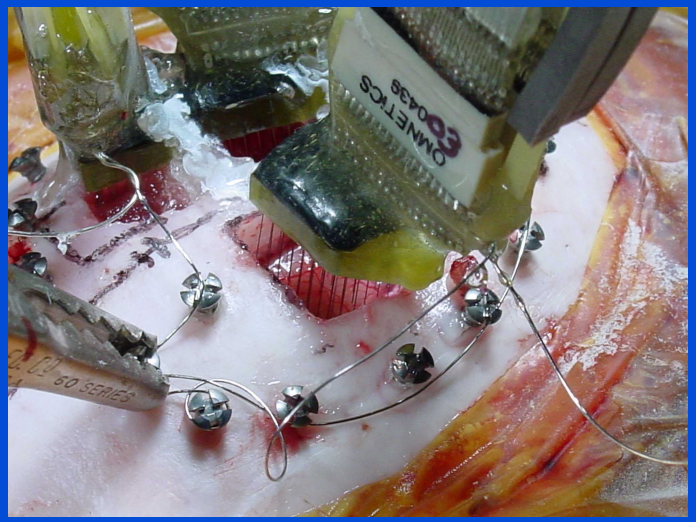
Crammond and Kalaska (2000)

Multielectrode Implant

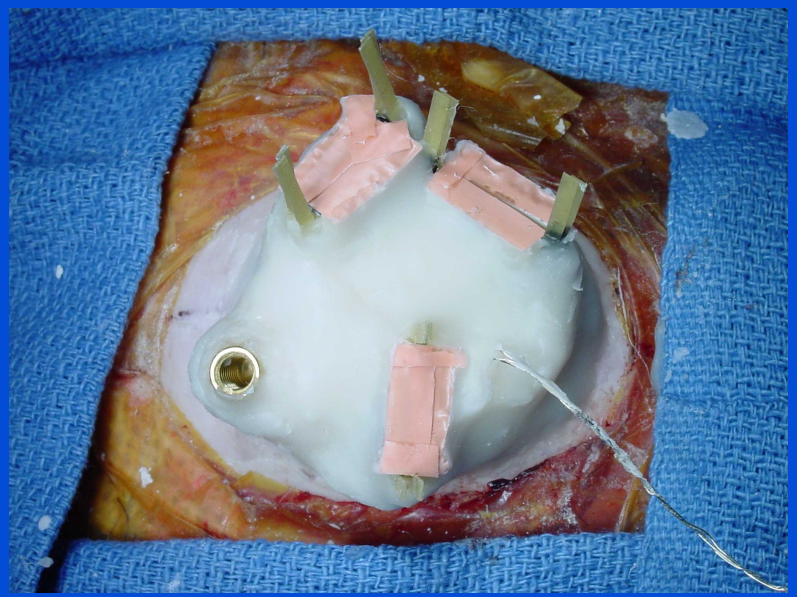
Craniotomies



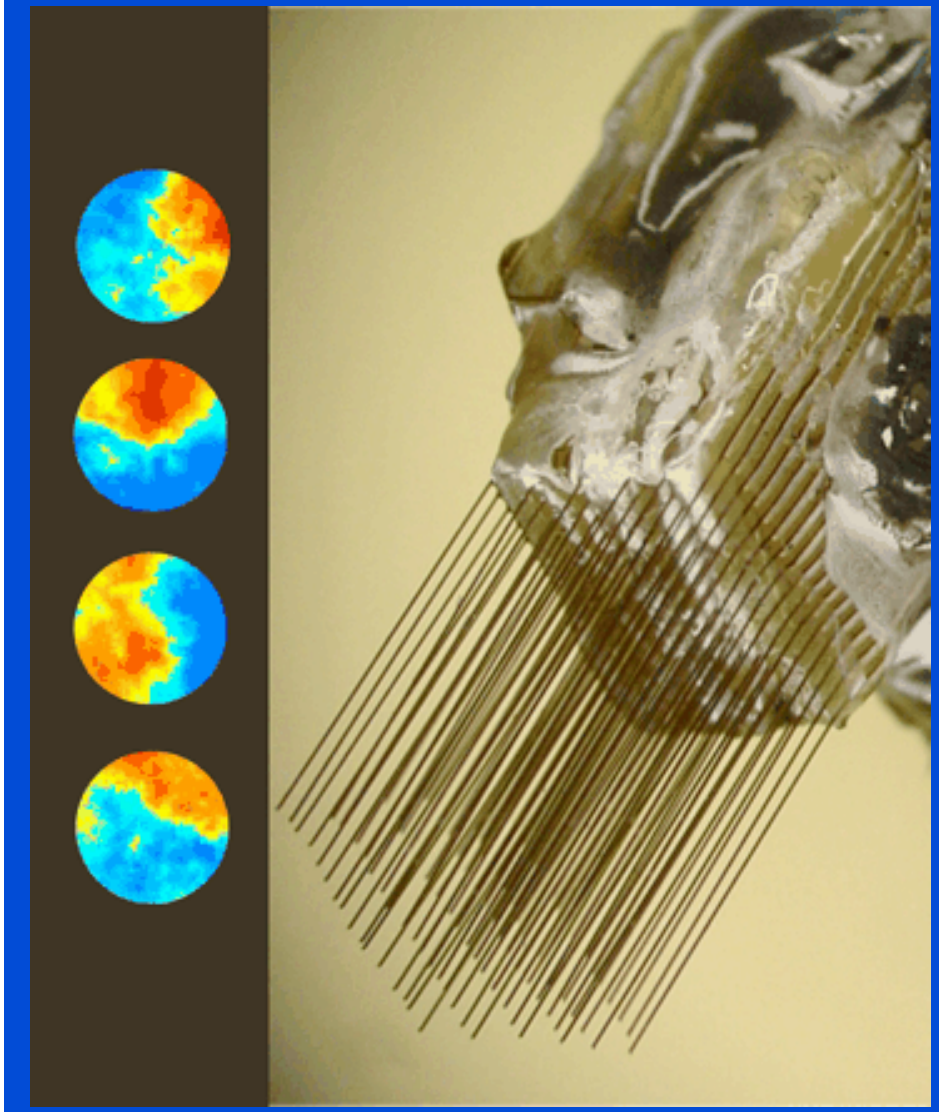
Insertion of Electrode Array

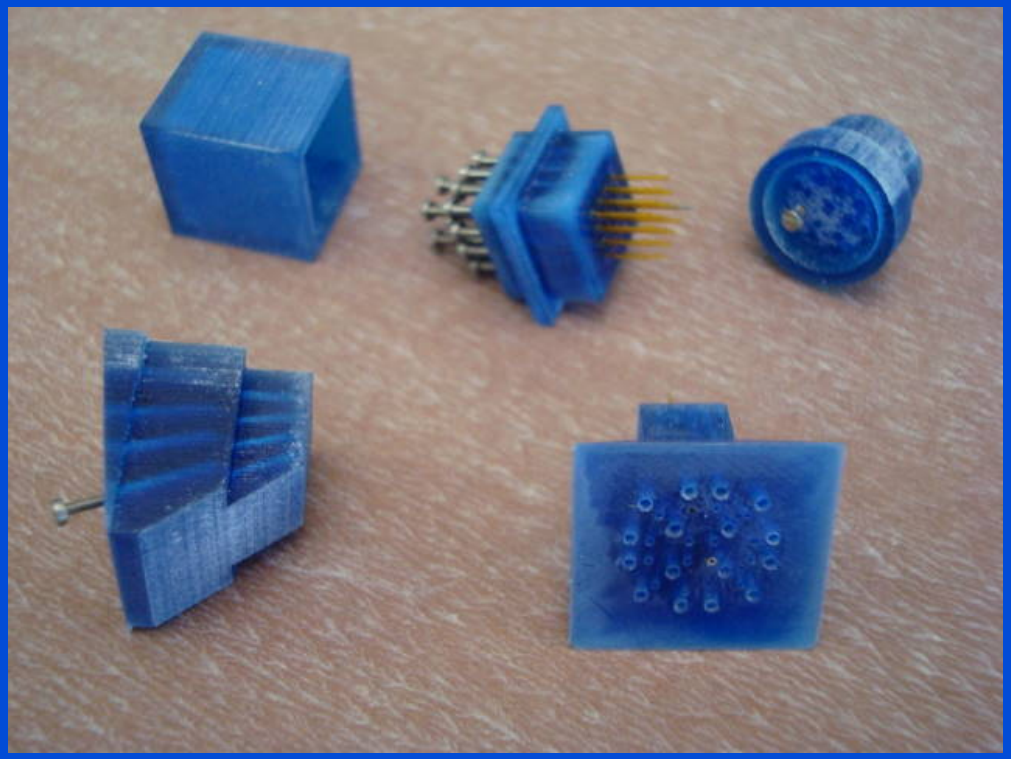


Completed Implant

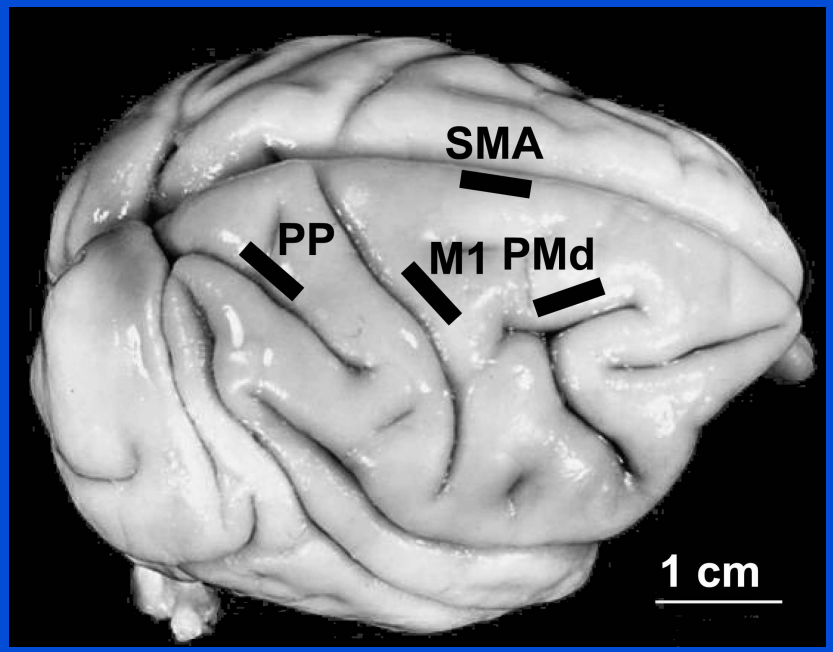


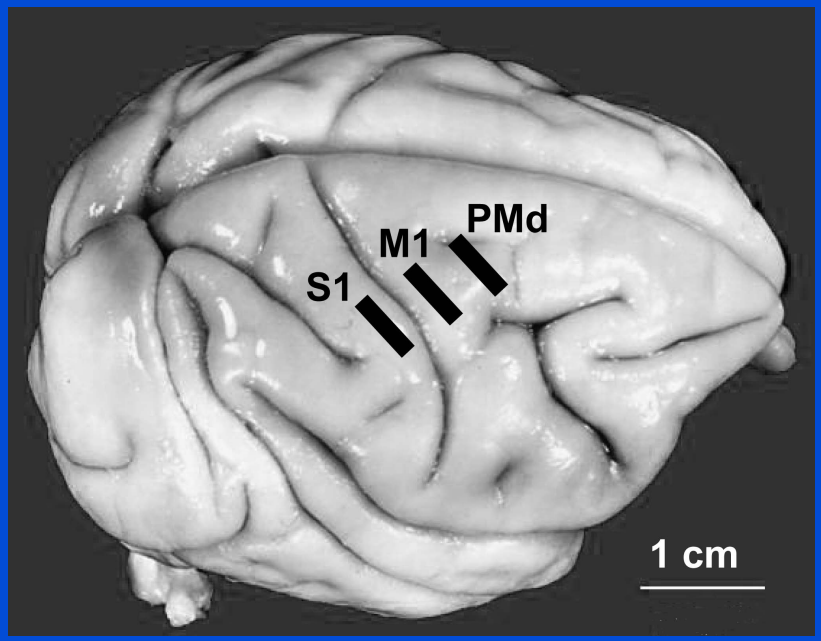
Multielectrode Implant

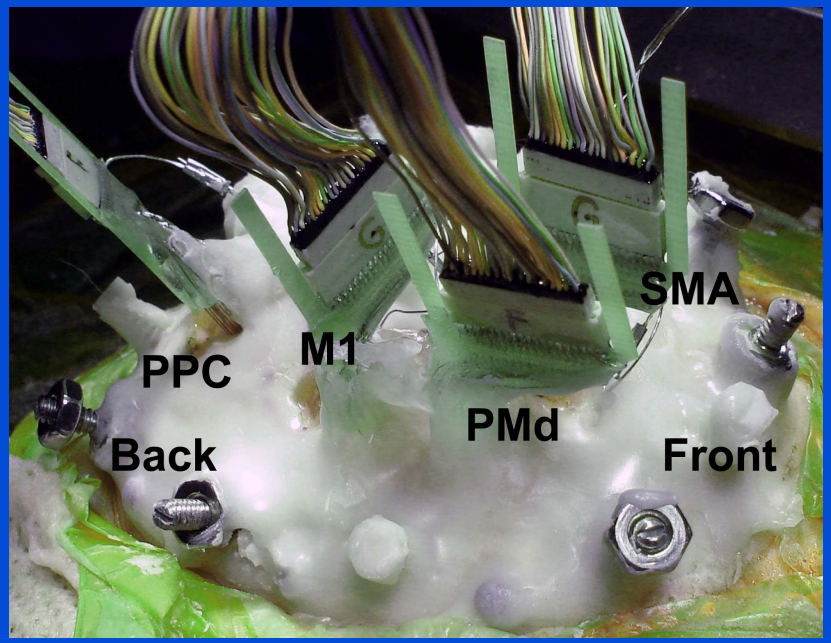


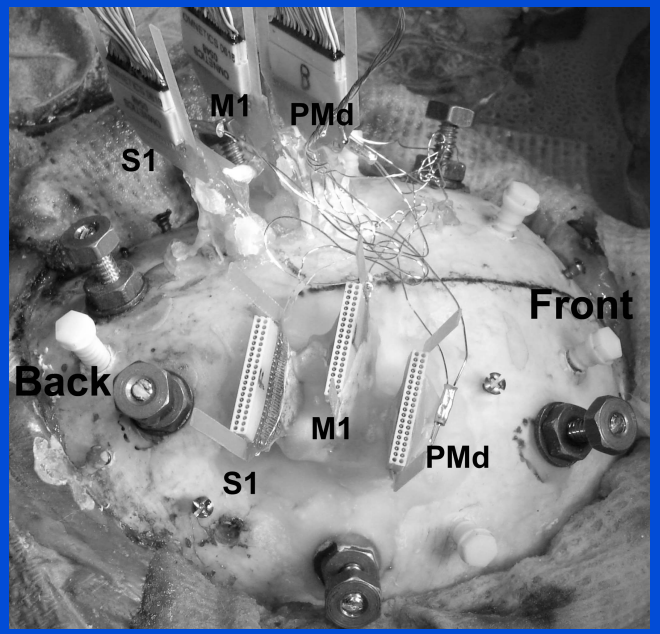


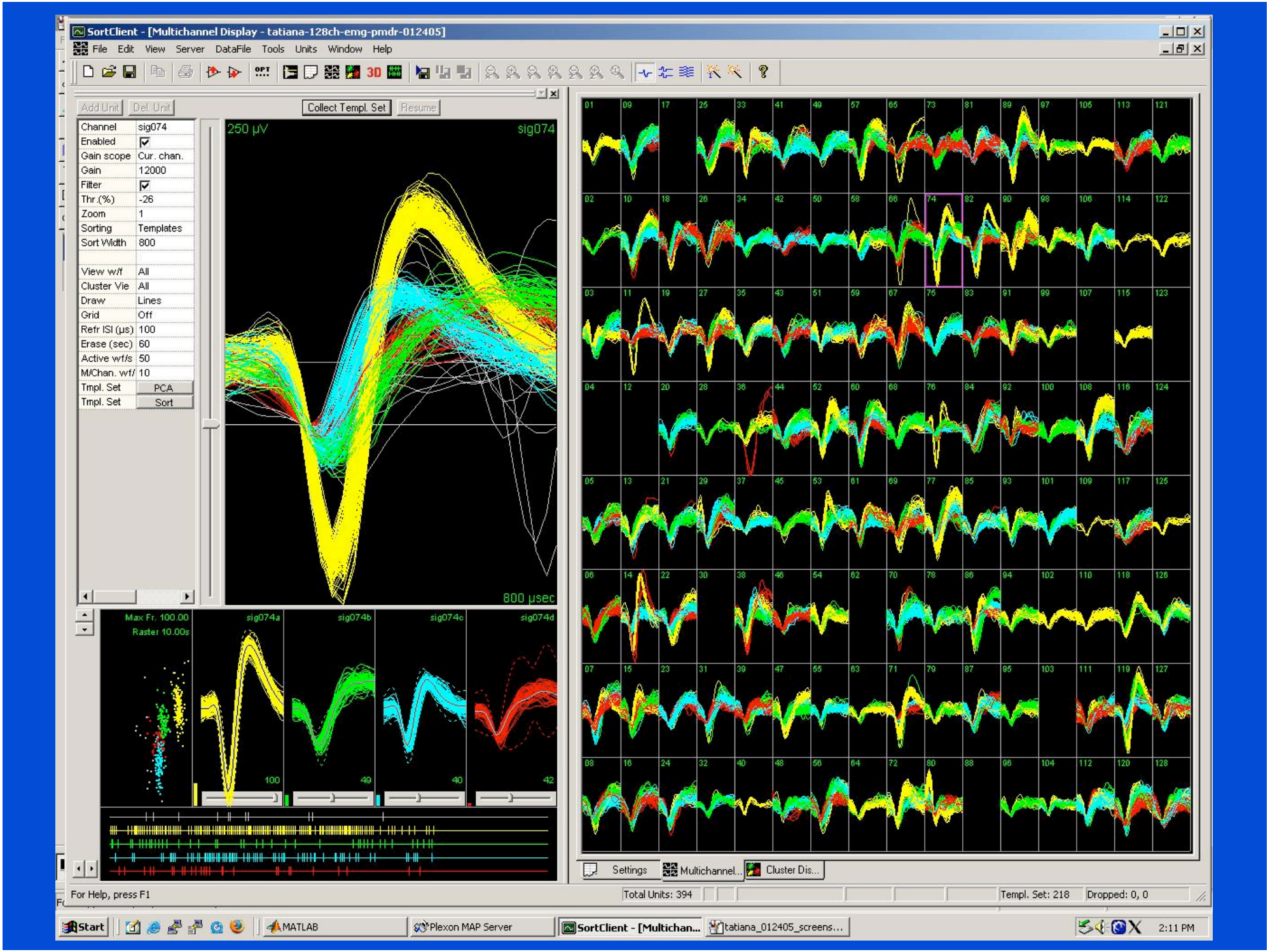
Example implants










SortClient - [Multichannel Display - tatiana-128ch-emg-pmdr-012405]
File Edit View Server DataFile Tools Units Window Help
Add Unit
Del. Unit
Collect Templ. Set
Resume
Channel sig074
Enabled
Gain scope Cur. chan.
Gain 12000
Filter
Thr.(%) -26
Zoom 1
Sorting Templates
Sort Width 800
View w/f All
Cluster Vie All
Draw Lines
Grid Off
Refr ISI (µs) 100
Erase (sec) 60
Active wf/s 50
M/Chan. wf/ 10
Tmpl. Set PCA
Tmpl. Set Sort
250 µV
sig074
800 µsec
Max Fr. 100.00
Raster 10.00s
sig074a
sig074b
sig074c
sig074d
100
49
40
42
Settings
Multichannel...
Cluster Dis...
For Help, press F1
Total Units: 394
Templ. Set: 218
Dropped: 0, 0
Start
MATLAB
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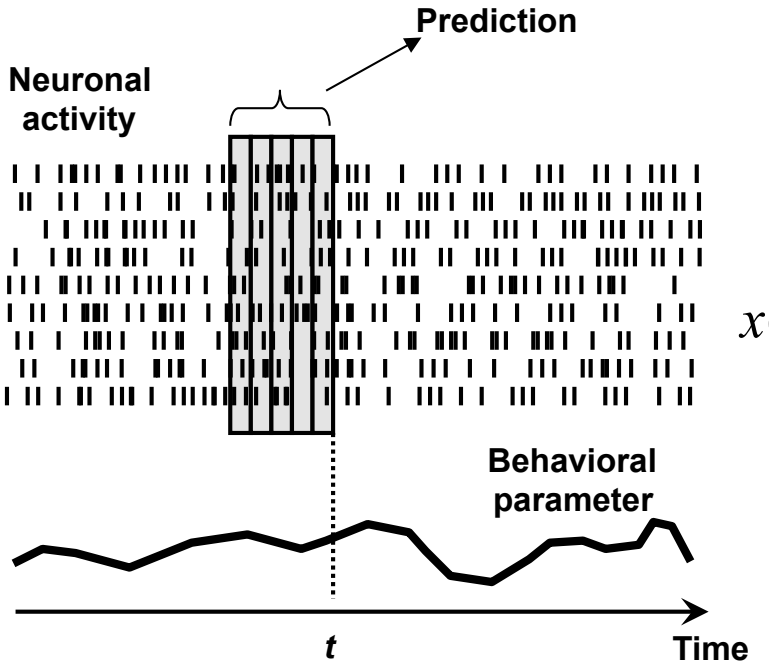
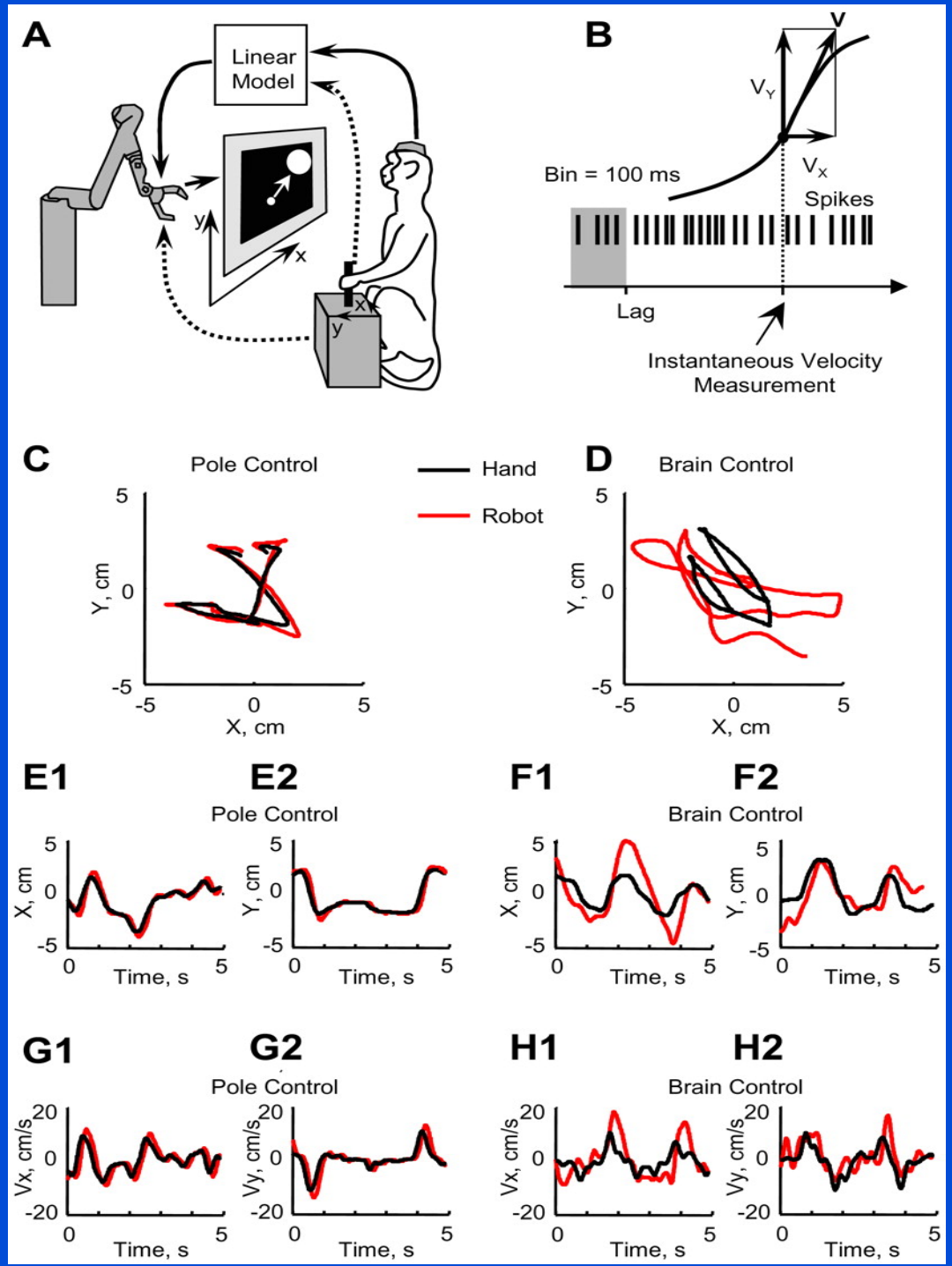
SortClient - [Multichan...
tatiana_012405_screens...
2:11 PM

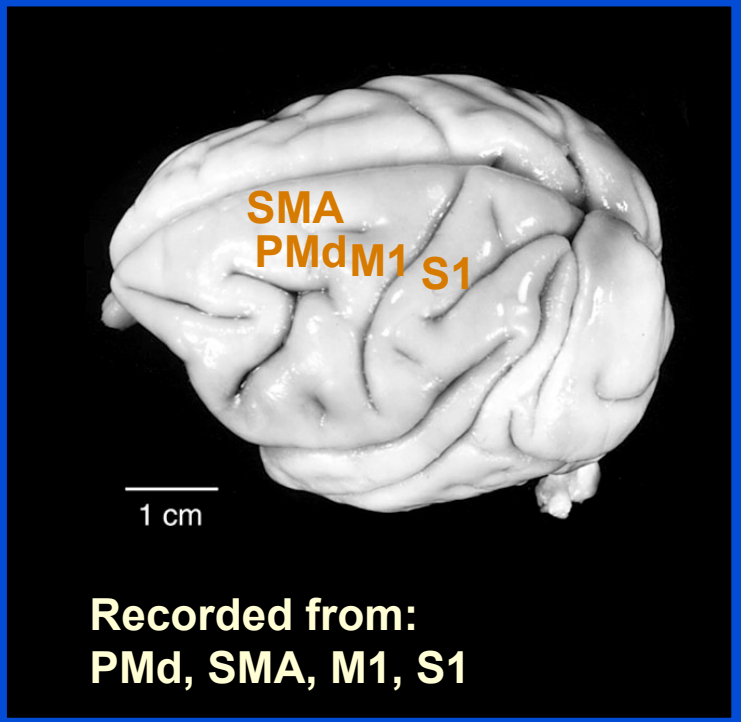
Decoding with linear model



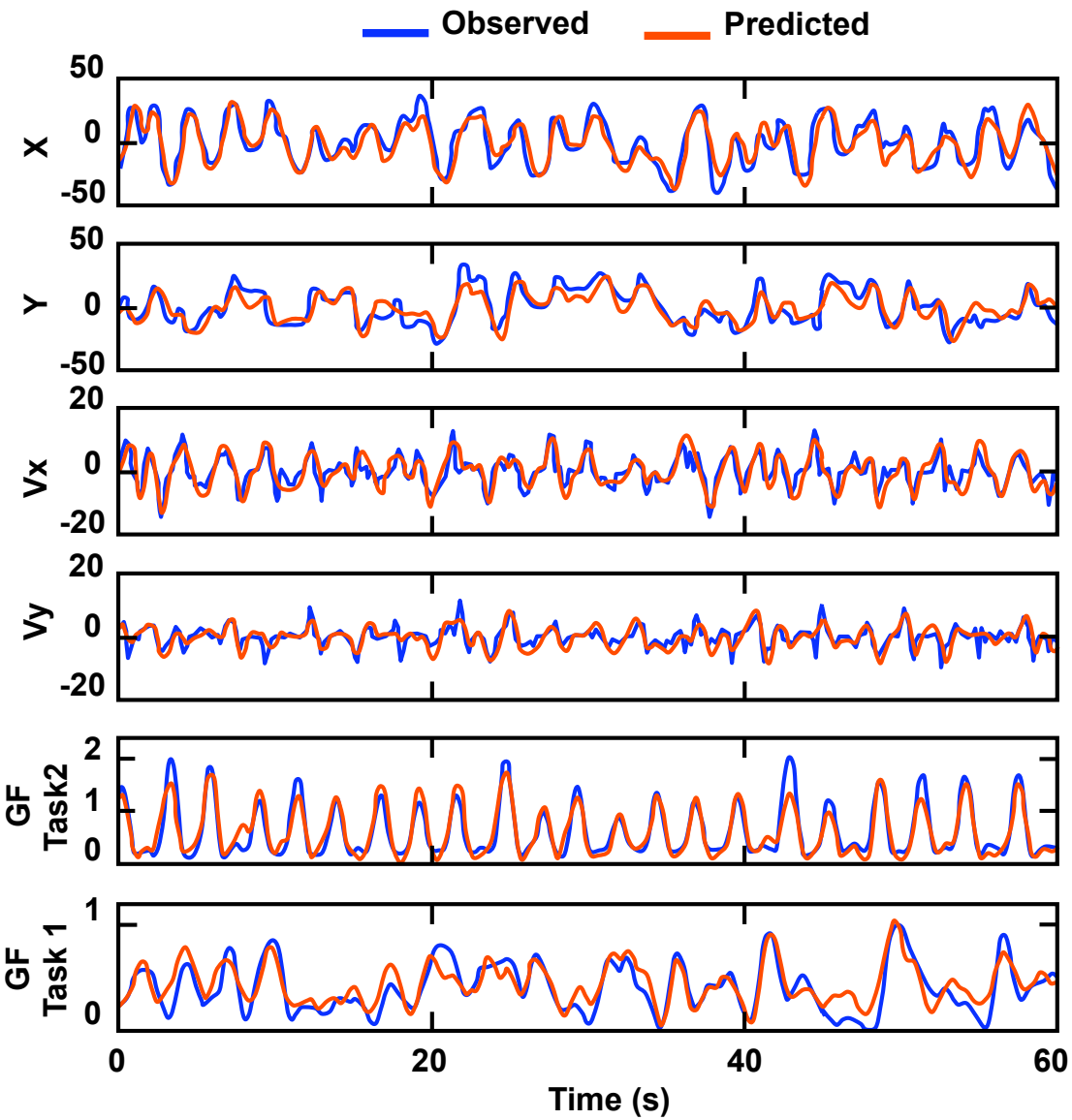
$$x(t) = x_0 + \sum_{neuron=1}^{N} \sum_{lag=0}^{T} W_{neuron}^{lag} Rate_{neuron}(t - lag) + \varepsilon$$

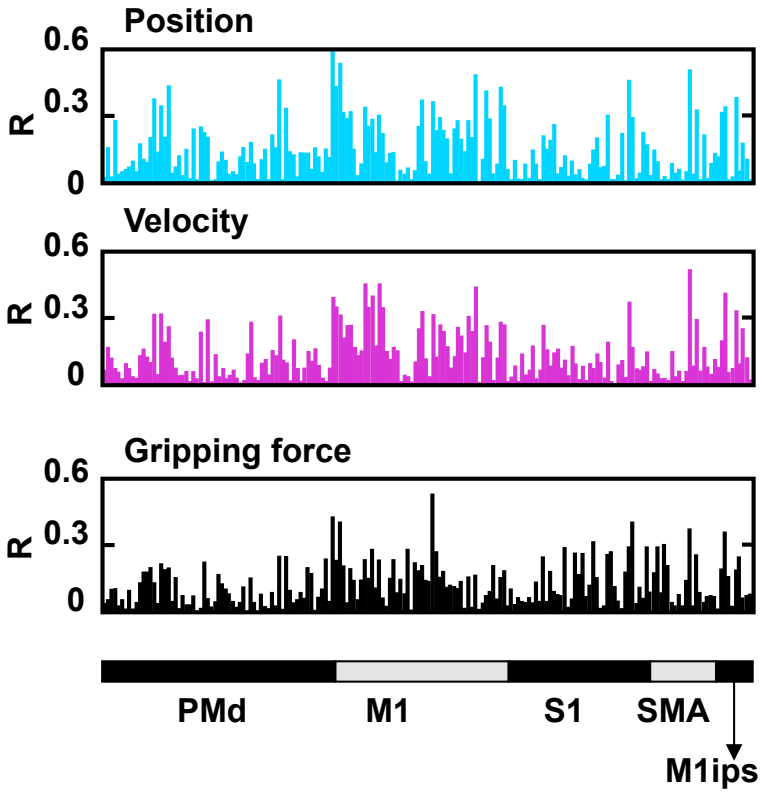


Real-time predictions of hand position

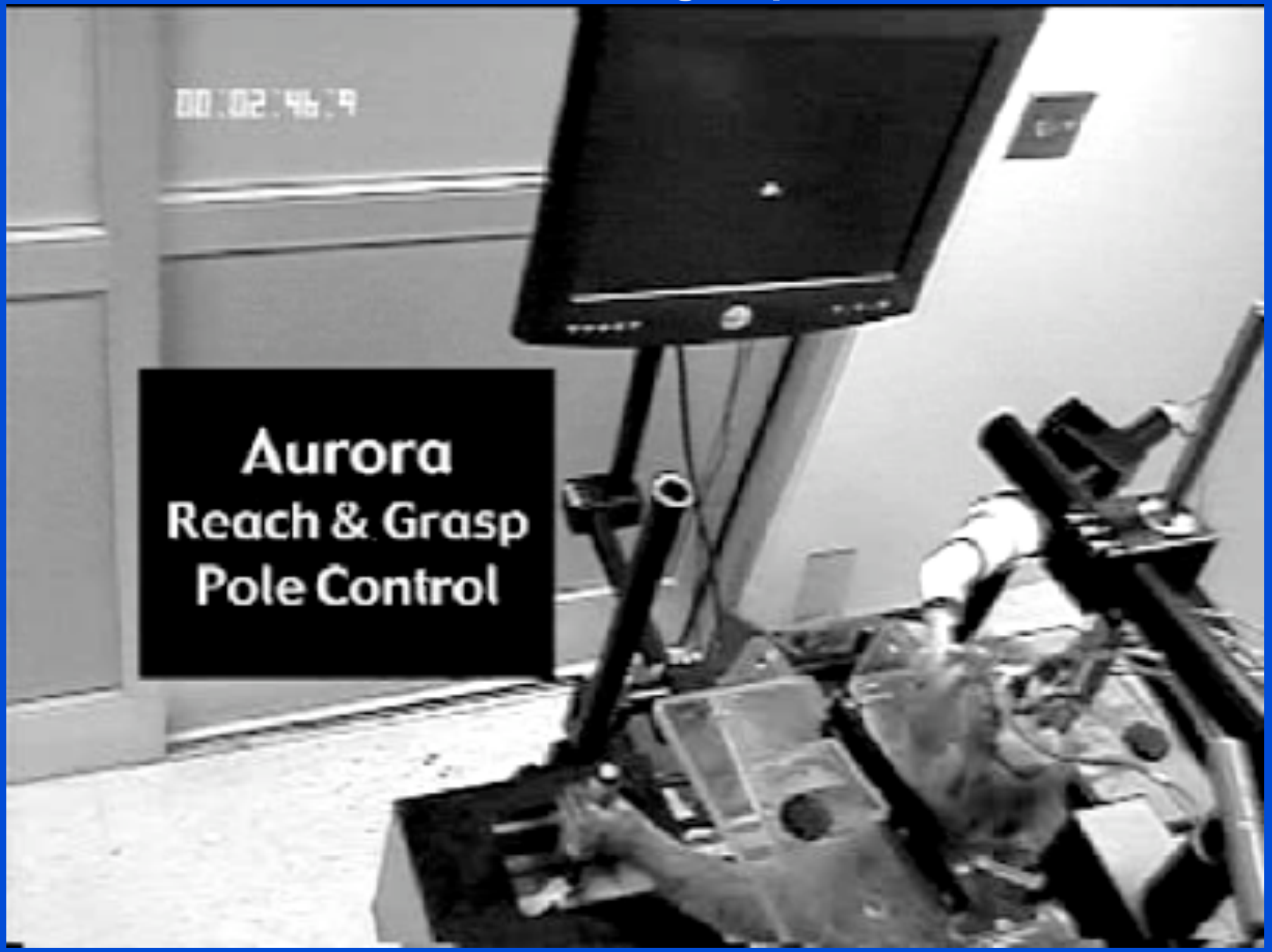


Prediction of Multiple Motor Variables

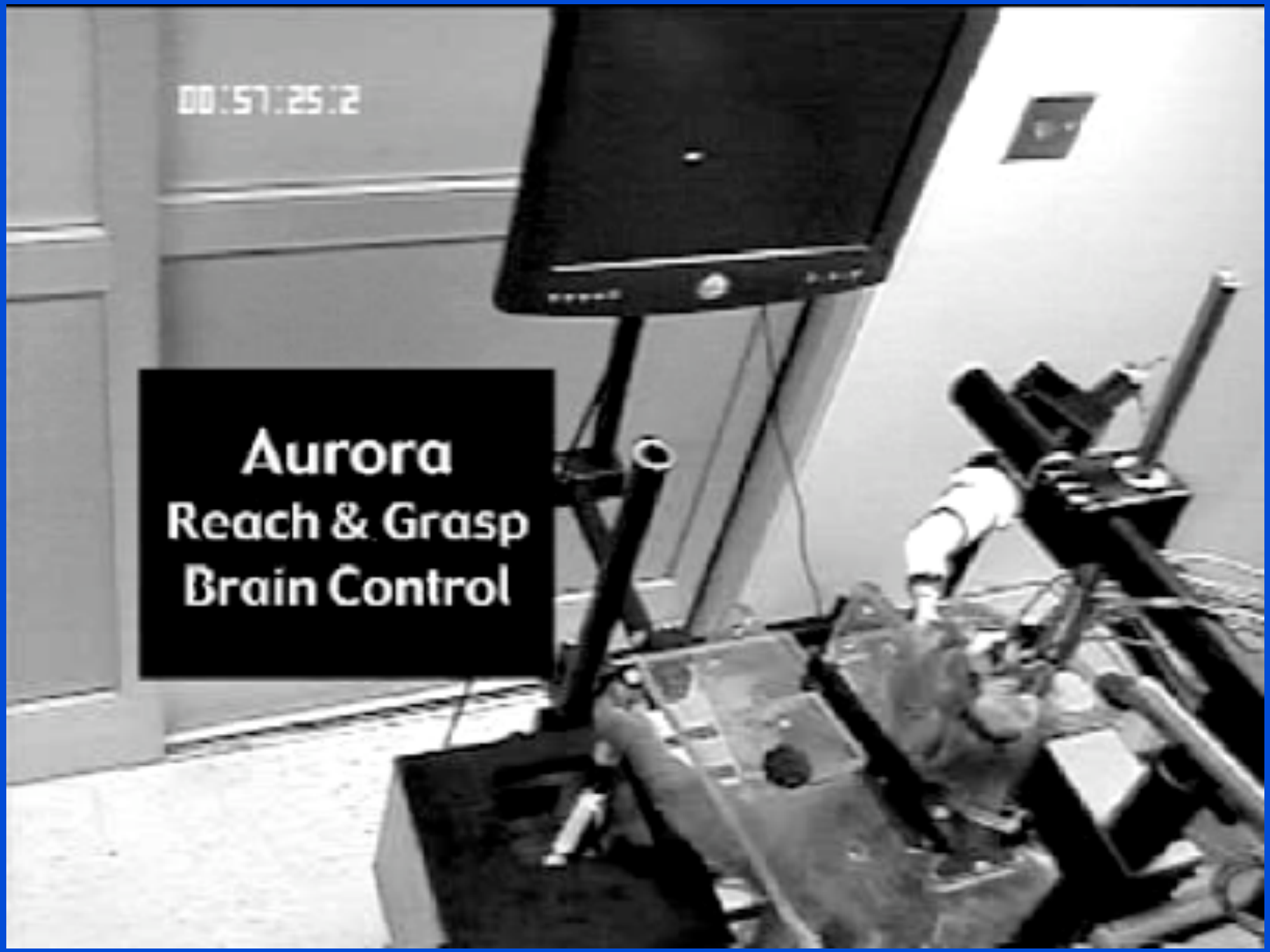




Reach and grasp task



Real-Time Predictions



Kalman filter in BMI design

State model

Observation model (tuning Curve)

Predict step

$$\mathbf{x}_{t'} = \mathbf{F}\mathbf{x}_{t-1}$$

$$\mathbf{P}_{t'} = \mathbf{F}\mathbf{P}_{t-1}\mathbf{F}^T + \mathbf{Q}$$

Update step

$$\mathbf{z}_t = \mathbf{H}\mathbf{x}_{t'}$$

$$\mathbf{S}_t = \mathbf{H}\mathbf{P}_{t'}\mathbf{H}^T + \mathbf{R}$$

$$\mathbf{K}_t = \mathbf{P}_{t'}\mathbf{H}^T\mathbf{S}_t^{-1}$$

$$\mathbf{x}_t = \mathbf{x}_{t'} + \mathbf{K}_t(\mathbf{y}_t - \mathbf{z}_t)$$

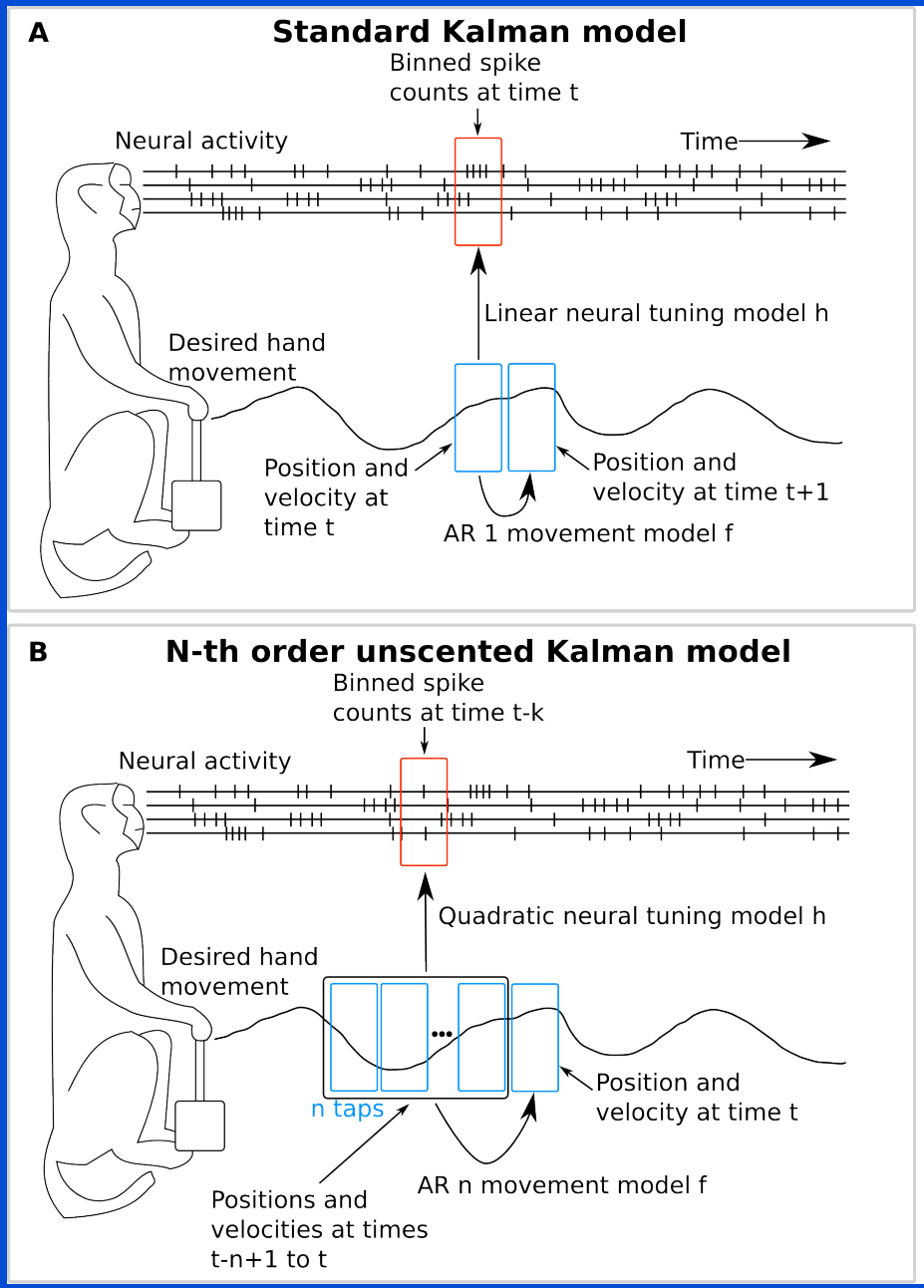
$$\mathbf{P}_t = (\mathbf{I} - \mathbf{K}_t\mathbf{H})\mathbf{P}_{t'}$$

State (e.g. arm position) predicted from the previous state

Neuronal rates predicted from the state

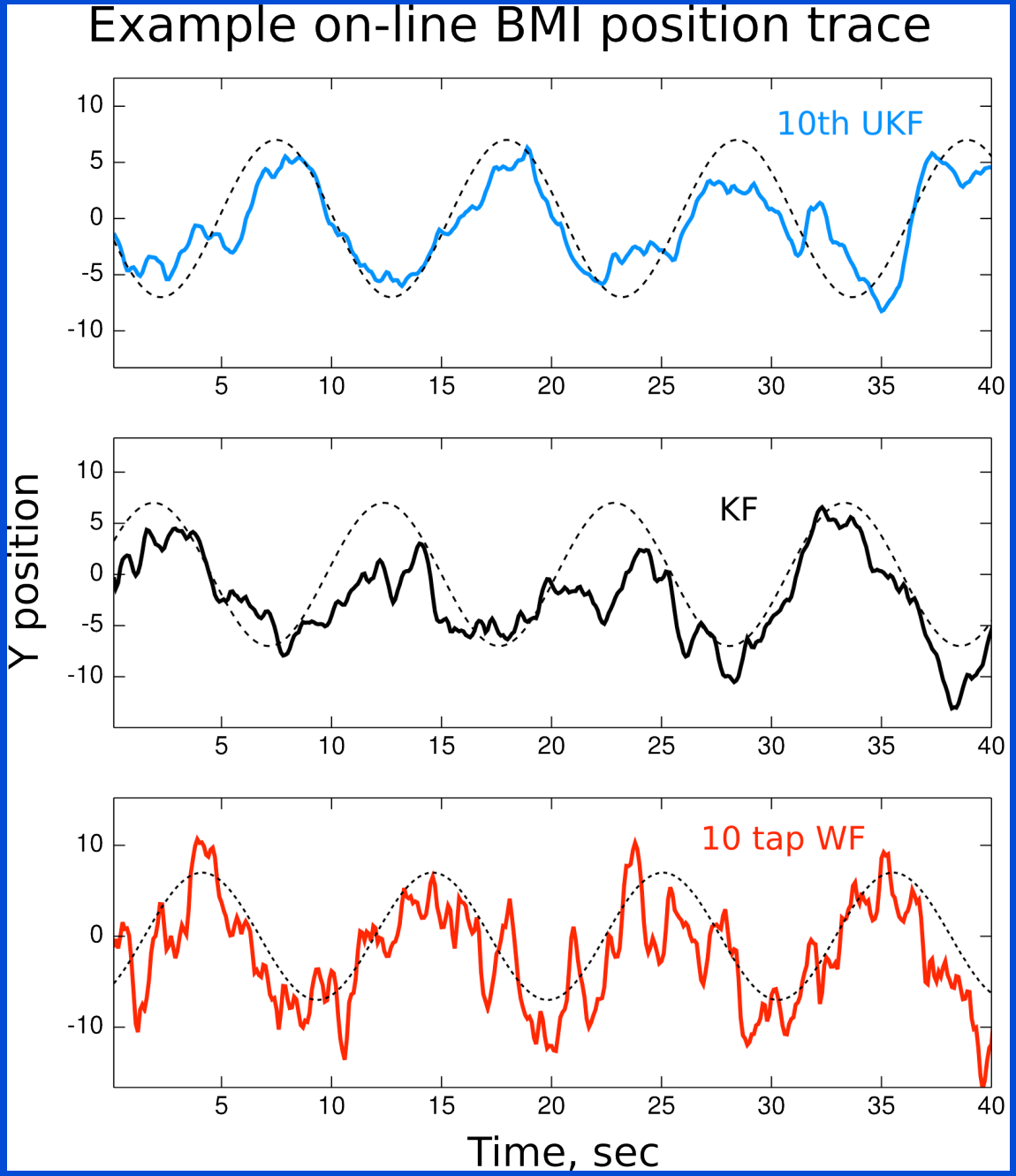
State prediction corrected based on the difference between actual and predicted rates

N-th order unscented Kalman filter



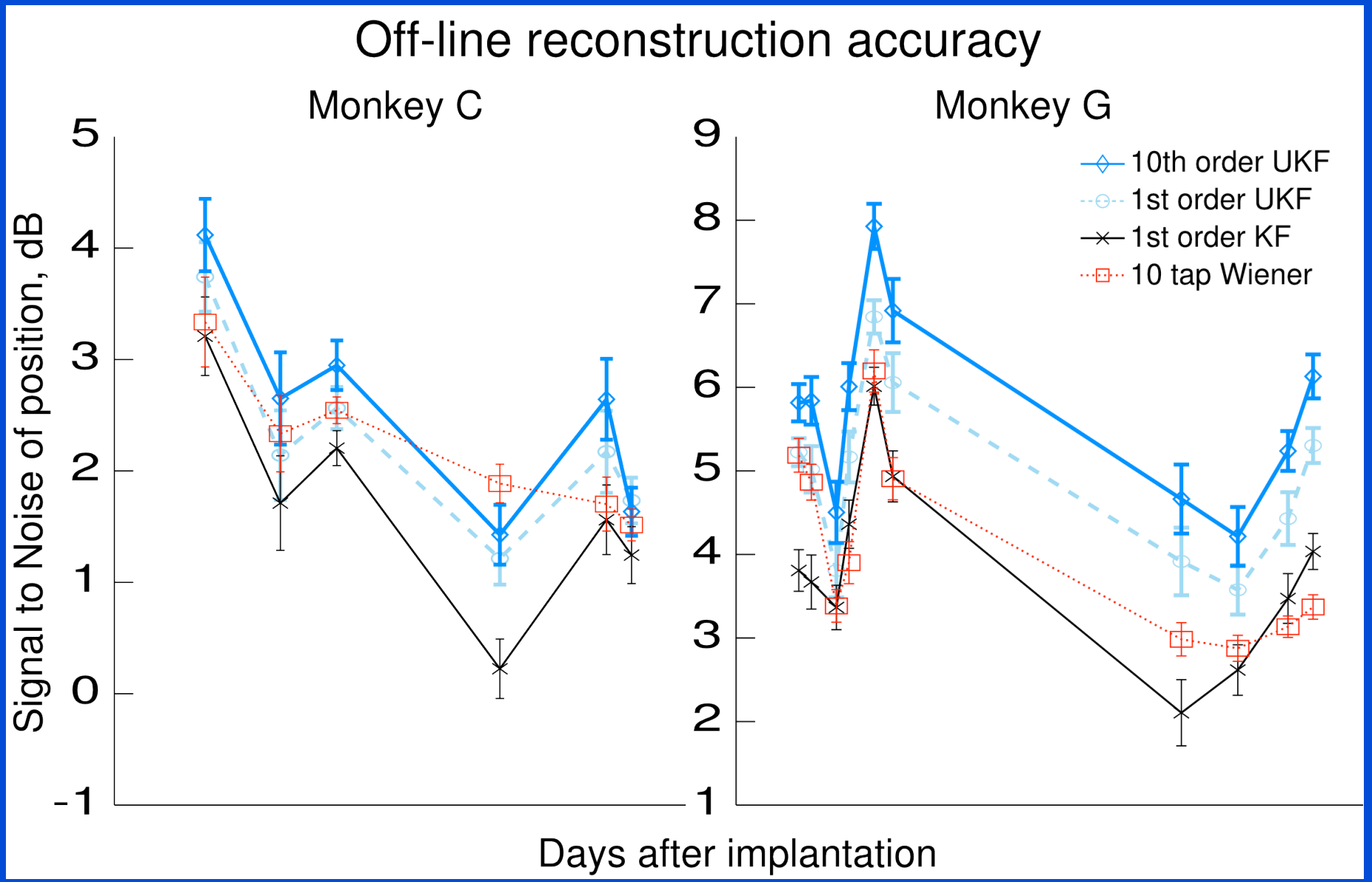
Li et al., unpublished

N-th order unscented Kalman filter



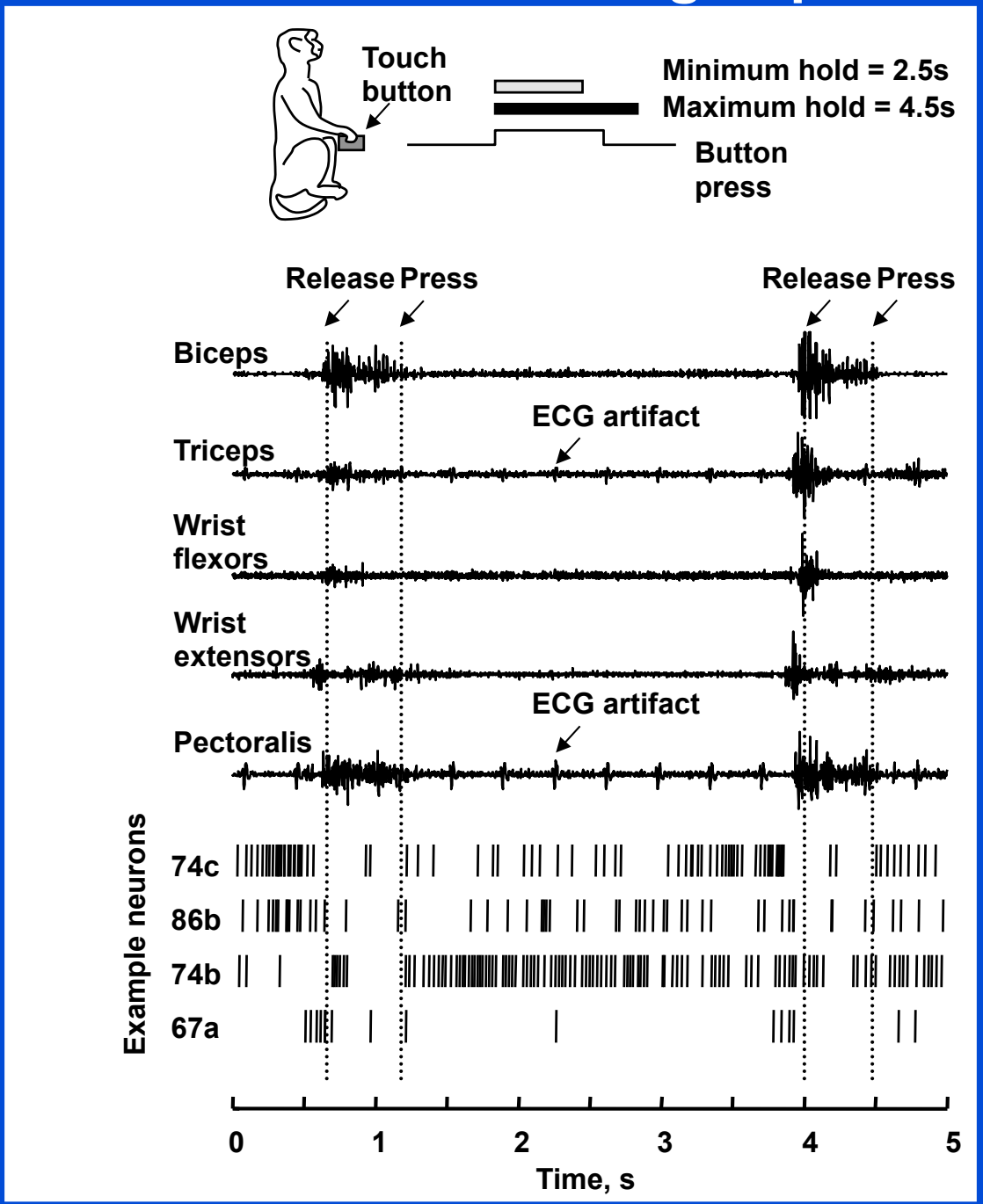
Li et al., unpublished

N-th order unscented Kalman filter

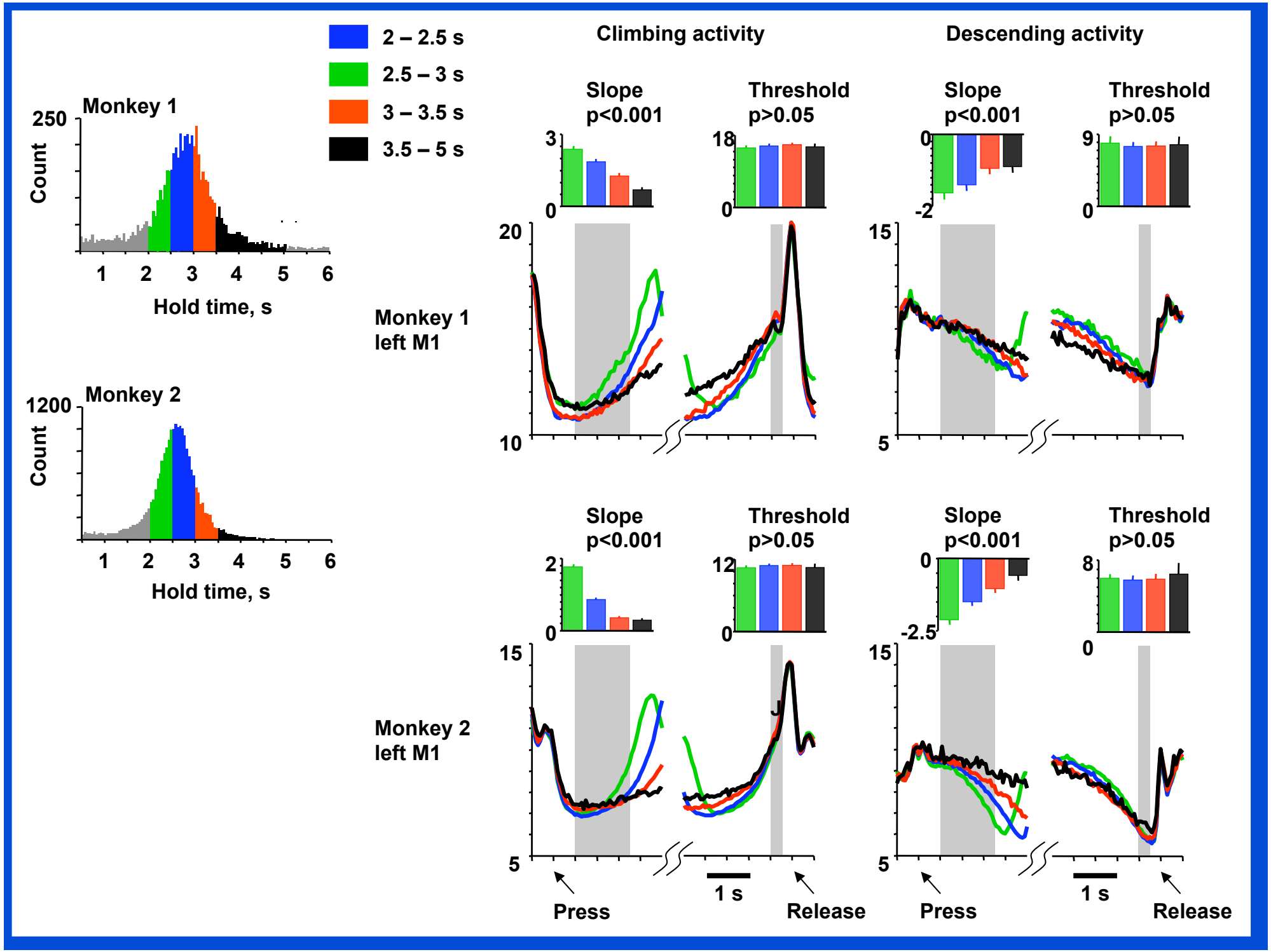


Li et al., unpublished

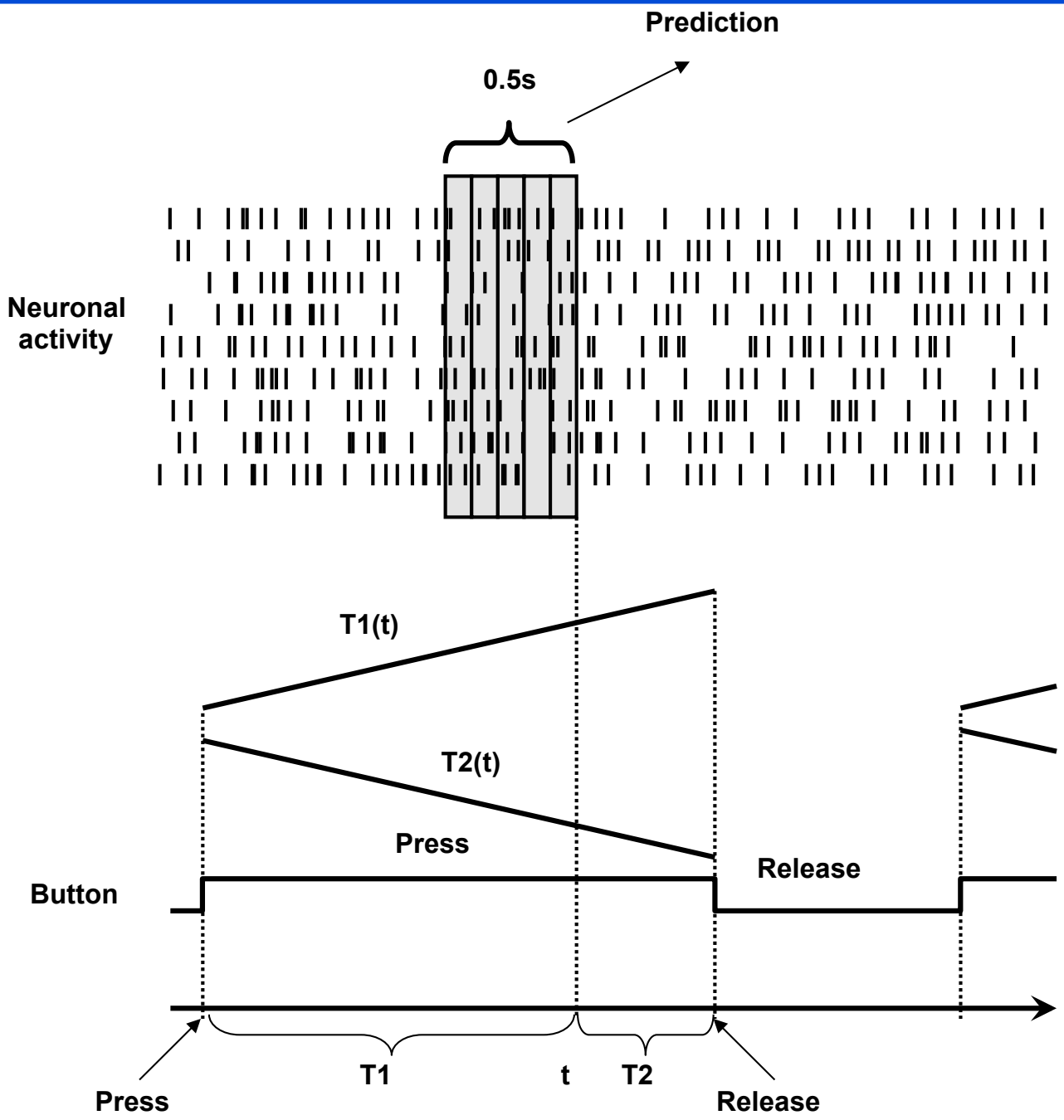
Timing Experiment



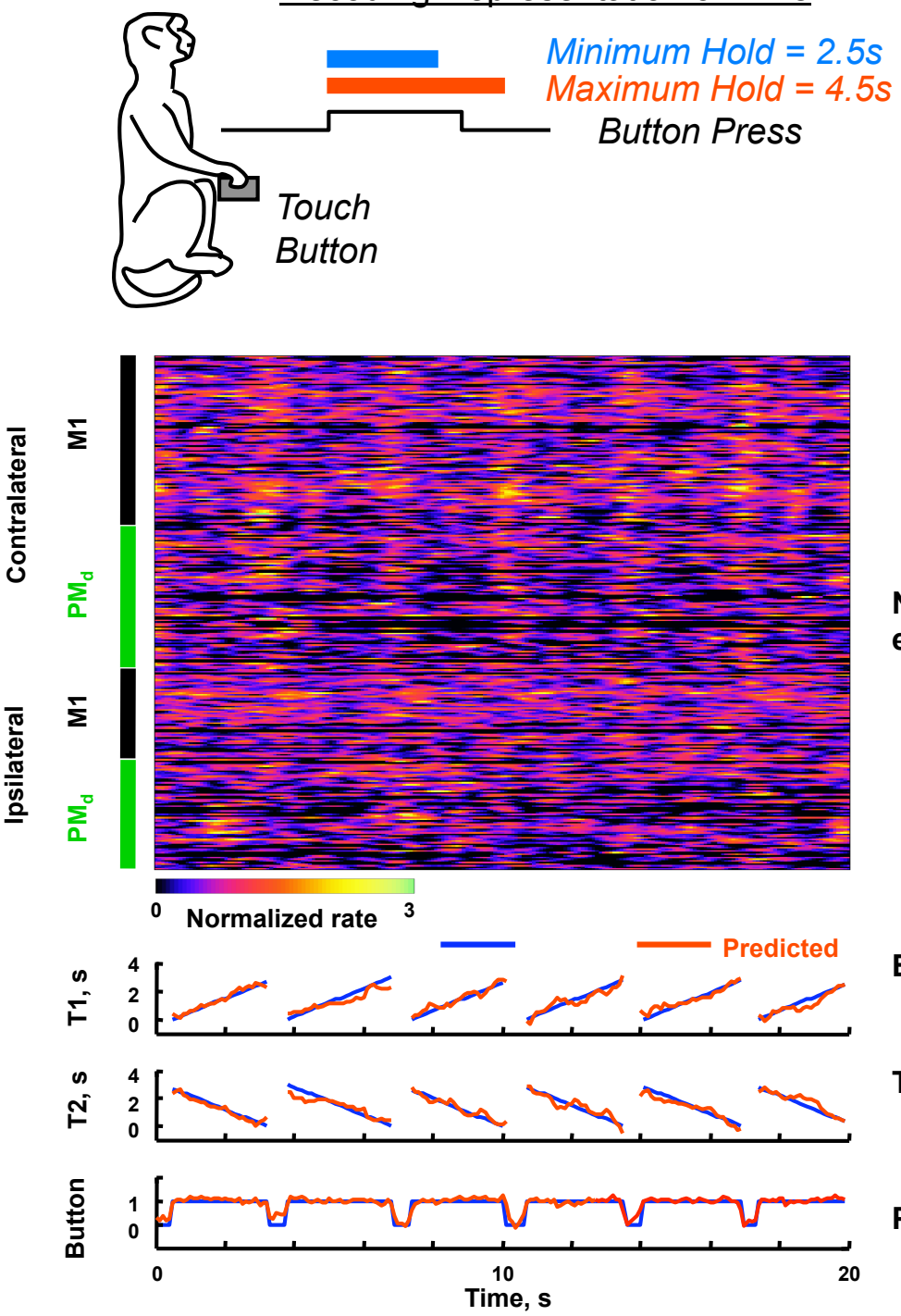
Lebedev et al., 2007


2 – 2.5 s
2.5 – 3 s
3 – 3.5 s
3.5 – 5 s
Monkey 1
250
Count
1
2
3
4
5
6
Hold time, s
Monkey 2
1200
Count
1
2
3
4
5
6
Hold time, s
Climbing activity
Descending activity
Slope
p<0.001
Threshold
p>0.05
Monkey 1
left M1
Monkey 2
left M1
1 s
Press
Release

Prediction of Time



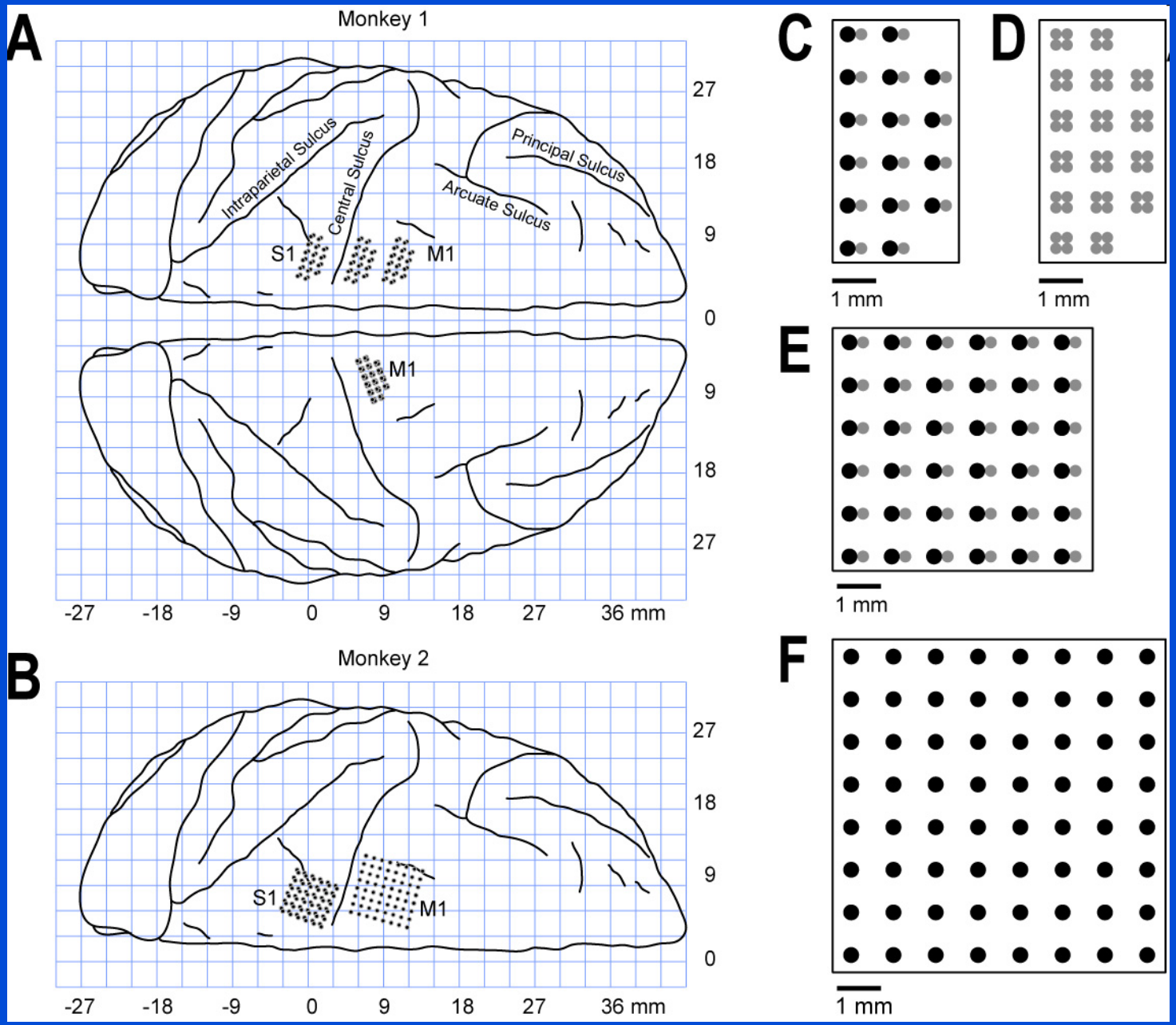
Decoding Representation of Time



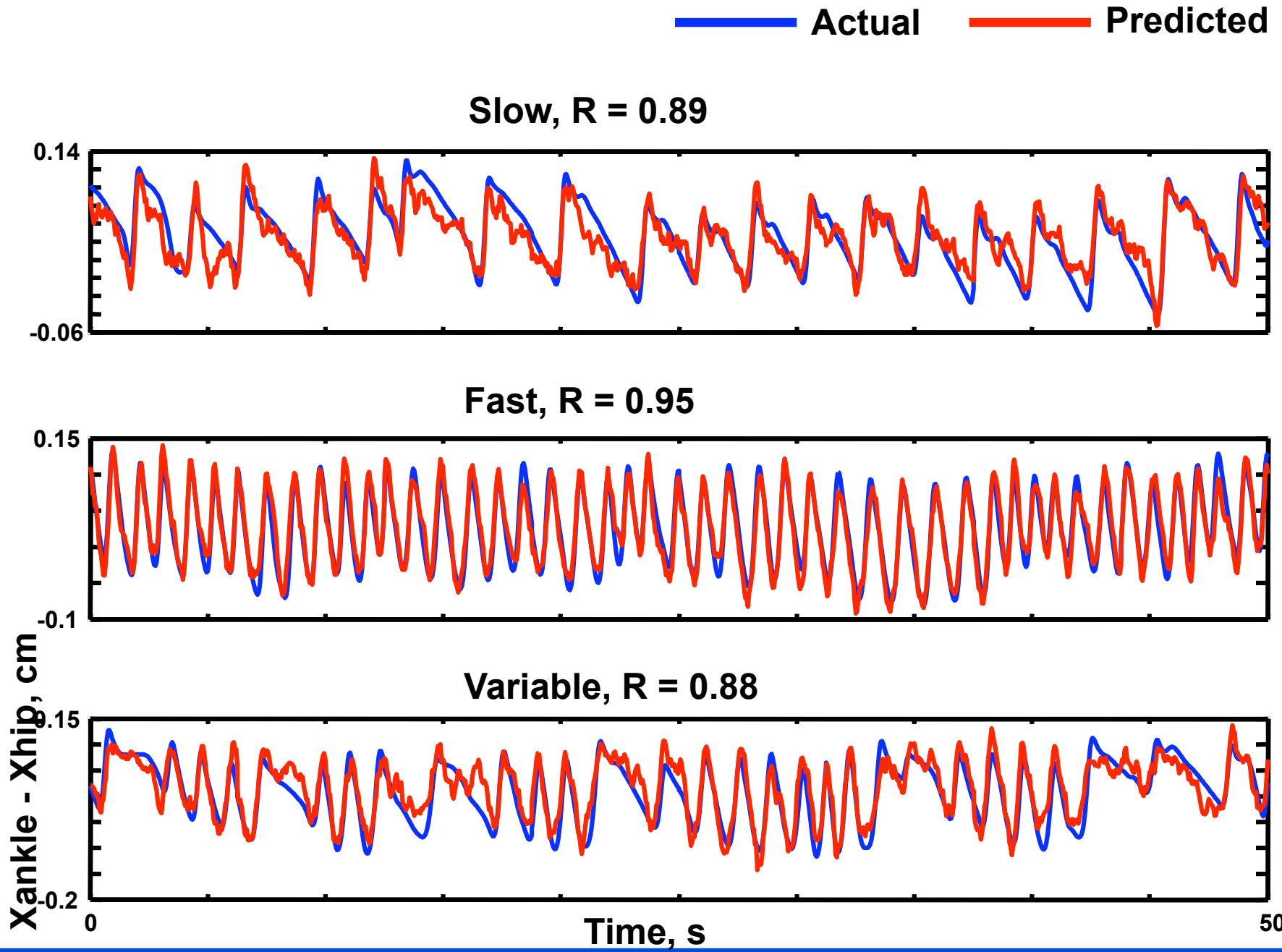
Monkey Locomotion

Monkey Locomotion

Leg Representation

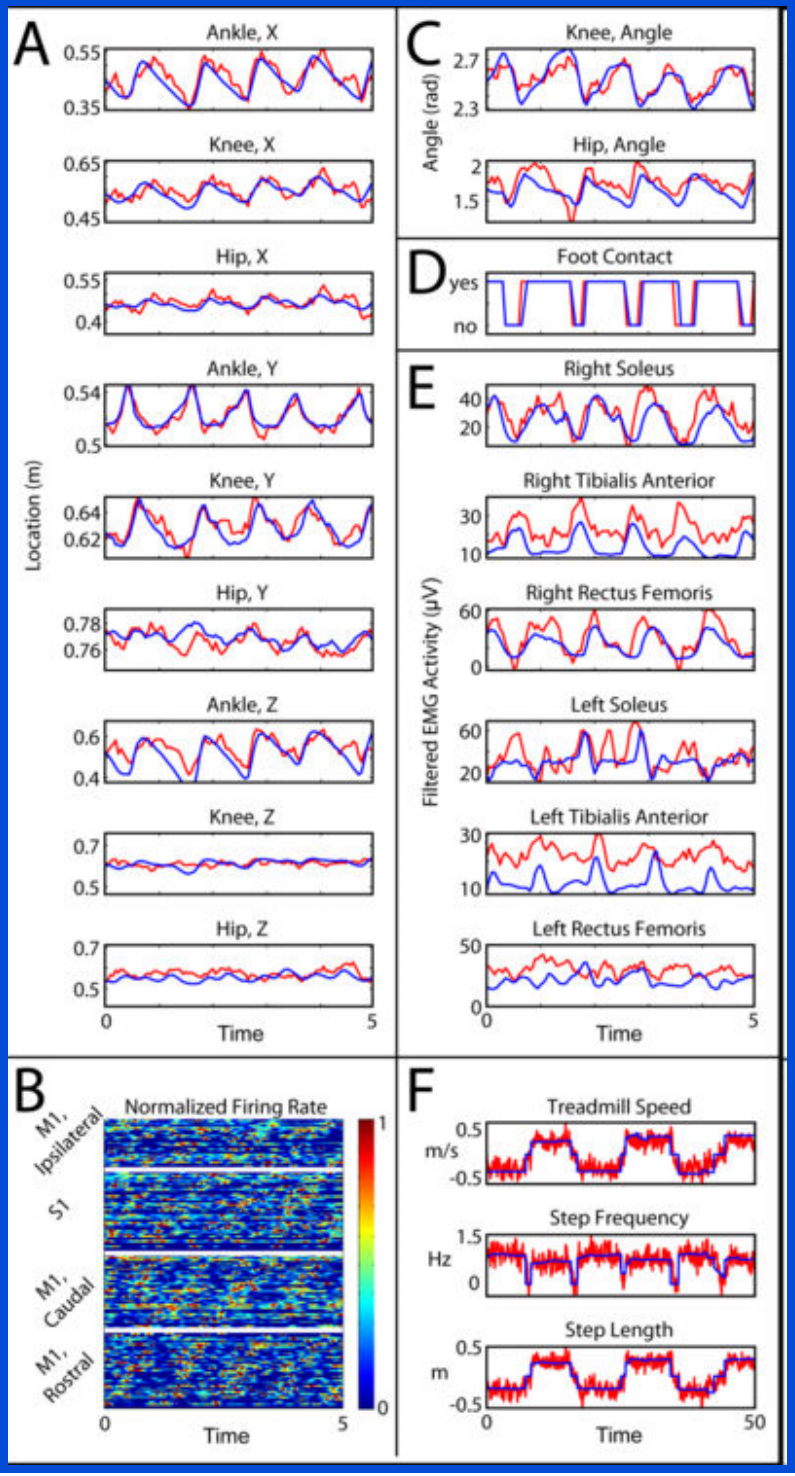


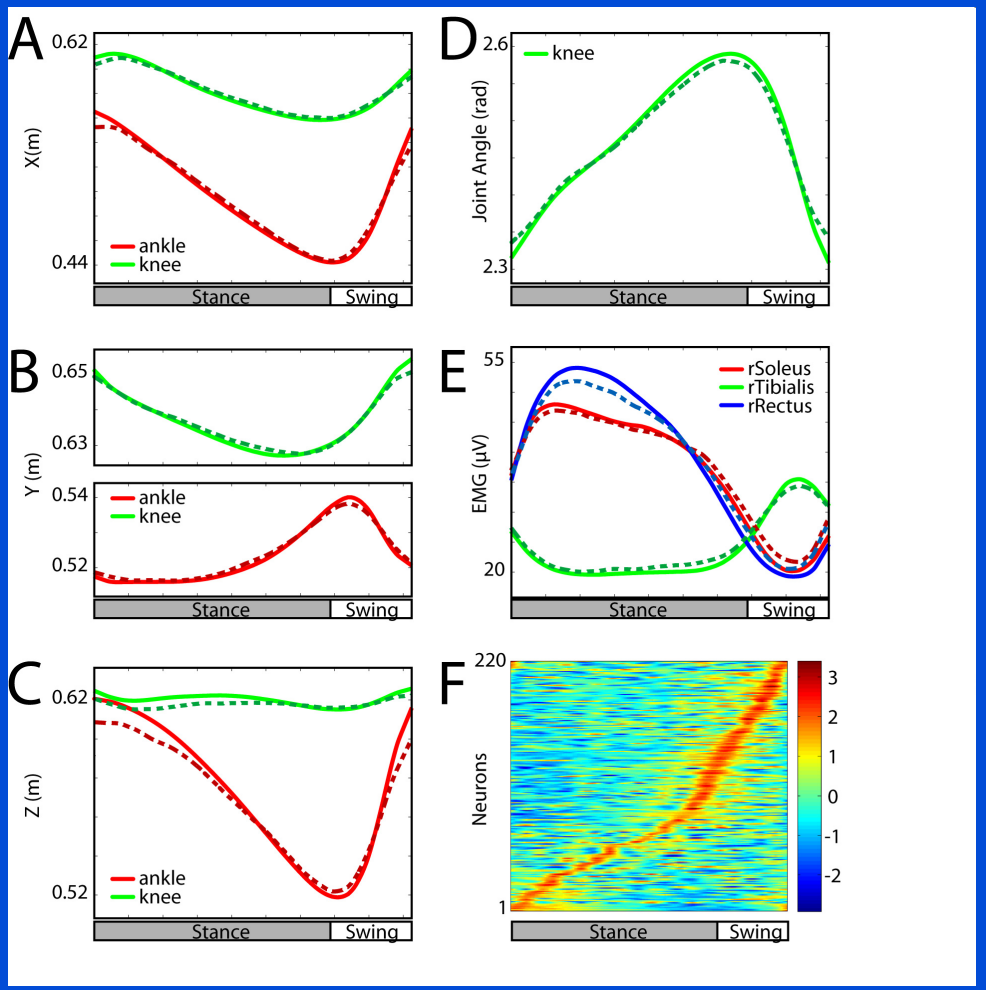
Fitzsimmons et al., unpublished



Fitzsimmons et al., unpublished

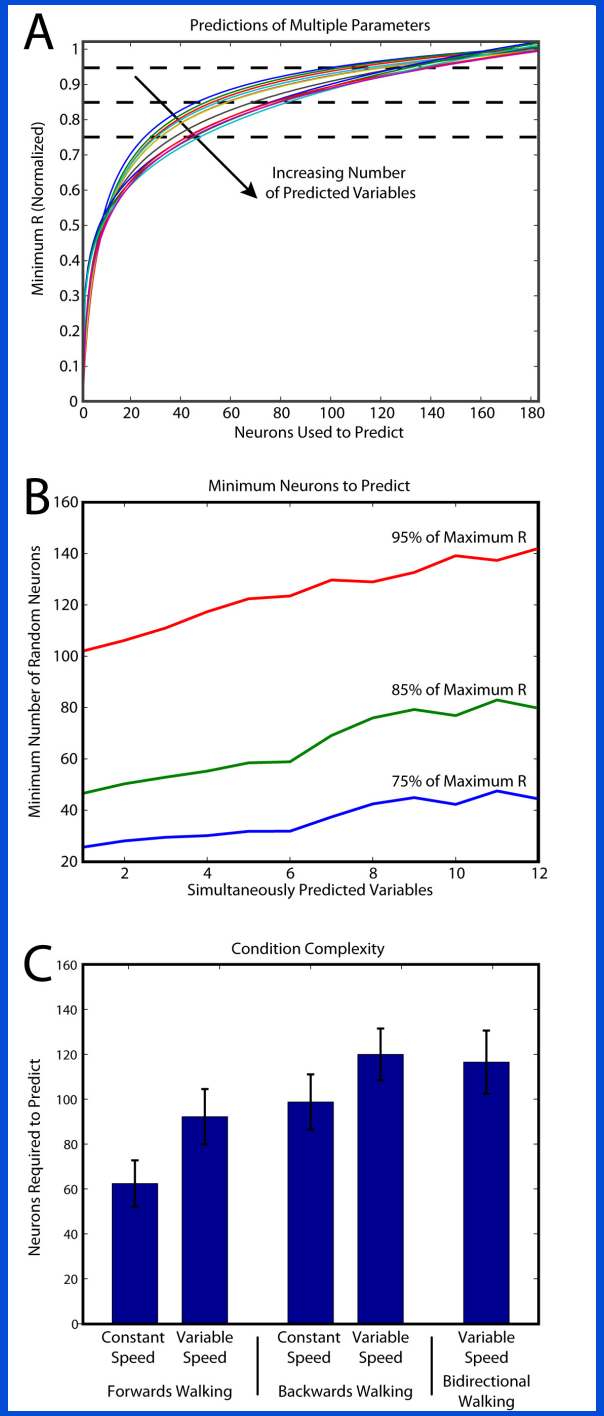
Decoding of multiple locomotion parameters



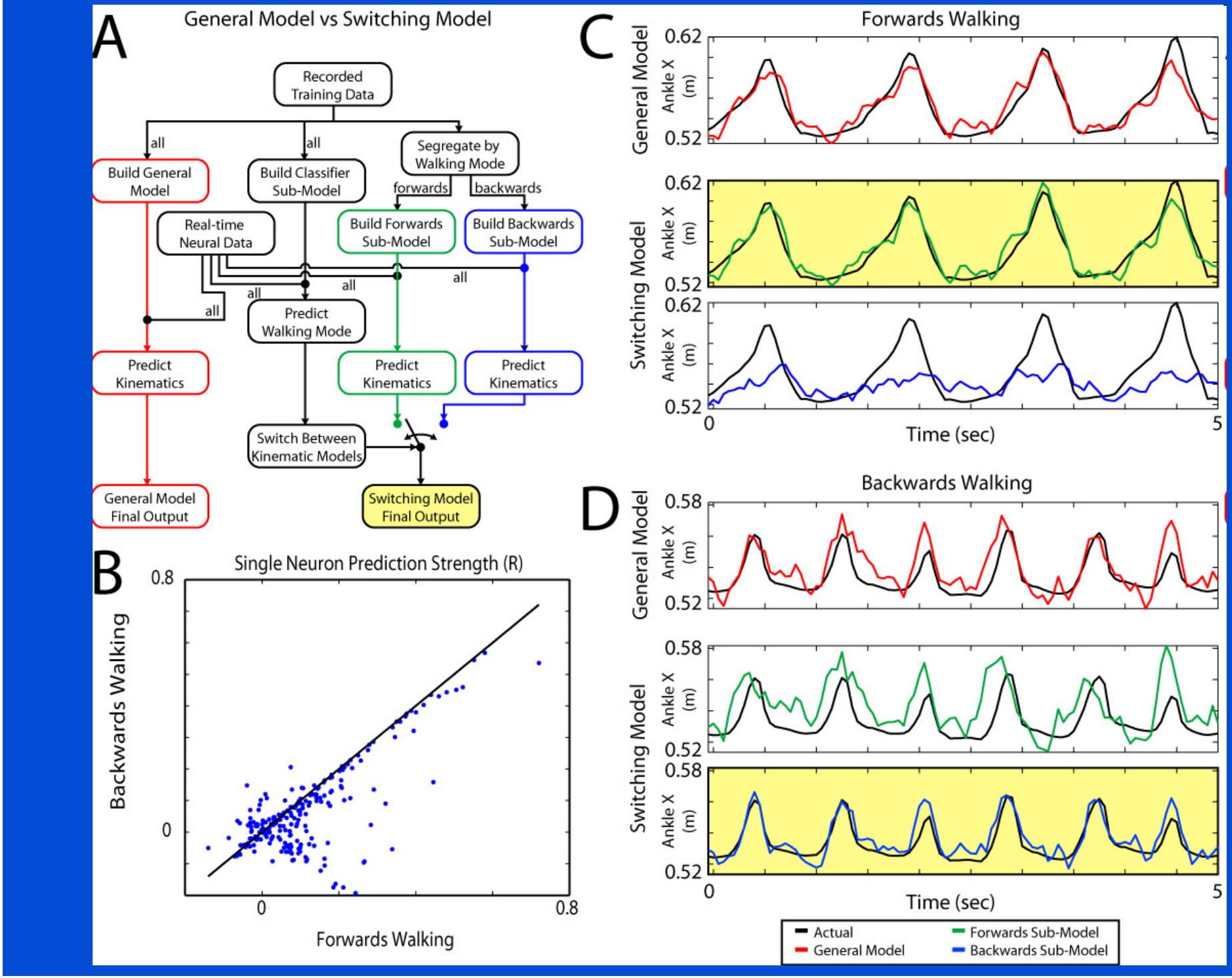


Fitzsimmons et al., unpublished

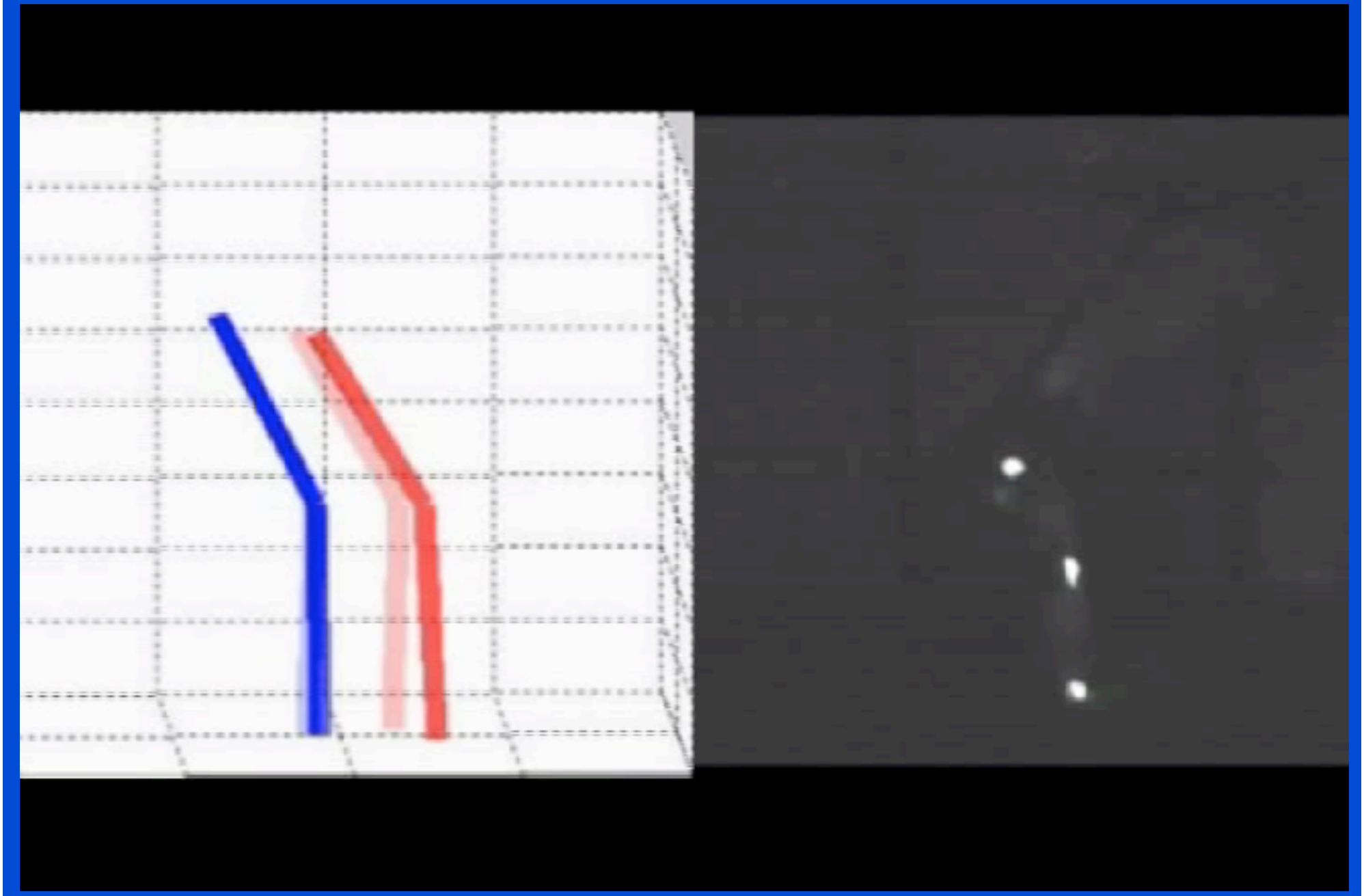
Decoding of multiple locomotion parameters



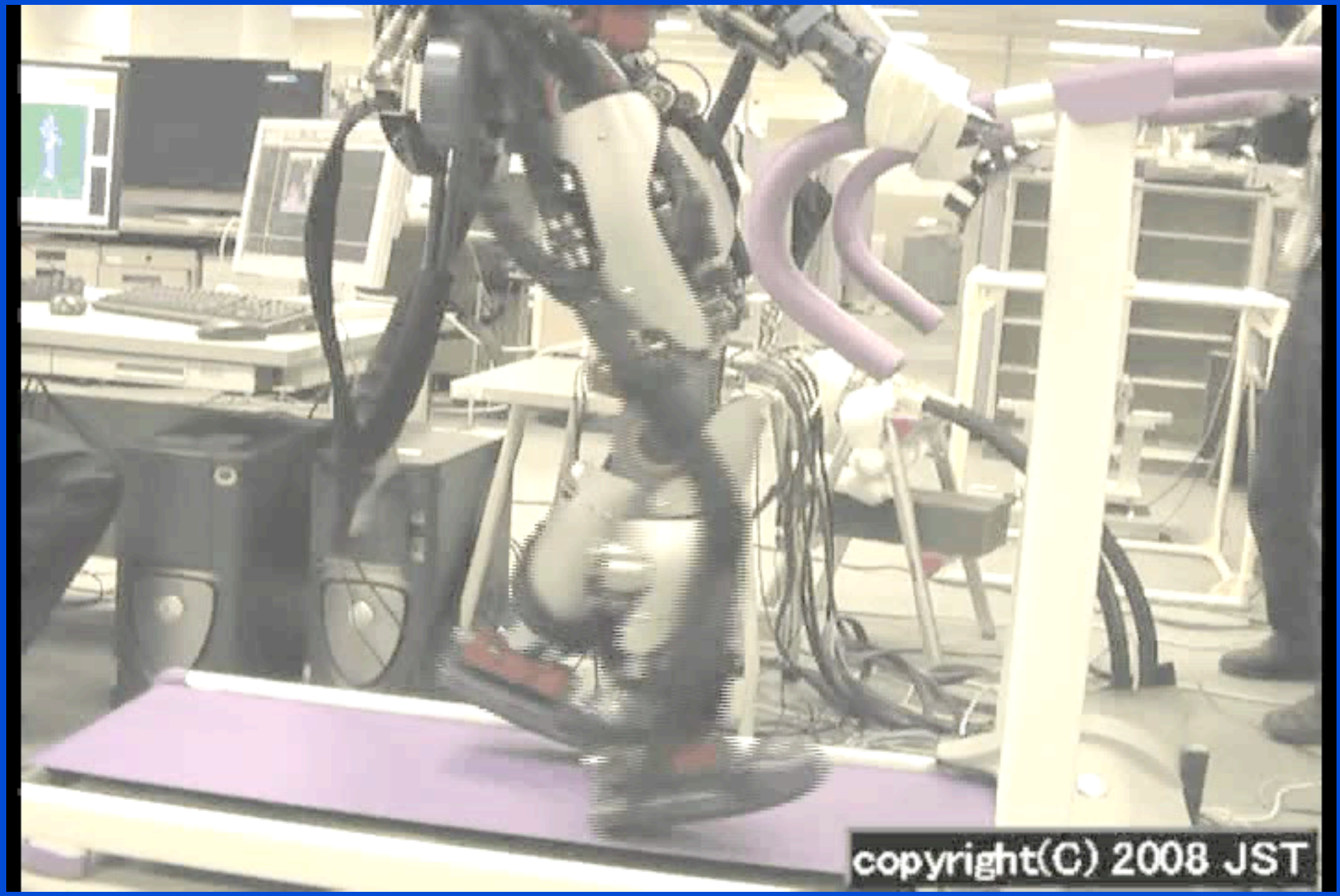
Fitzsimmons et al., unpublished


A
General Model vs Switching Model
Recorded Training Data
all
all
Segregate by Walking Mode
forwards
backwards
Build General Model
Build Classifier Sub-Model
Build Forwards Sub-Model
Build Backwards Sub-Model
Real-time Neural Data
all
all
all
all
all
Predict Walking Mode
Predict Kinematics
Predict Kinematics
Predict Kinematics
Switch Between Kinematic Models
General Model Final Output
Switching Model Final Output
B
Single Neuron Prediction Strength (R)
0.8
0
0
0.8
Backwards Walking
Forwards Walking
C
Forwards Walking
General Model
Switching Model
Ankle X (m)
0.62
0.52
0
5
Time (sec)
D
Backwards Walking
0.58
0.52
Actual
General Model
Forwards Sub-Model
Backwards Sub-Model

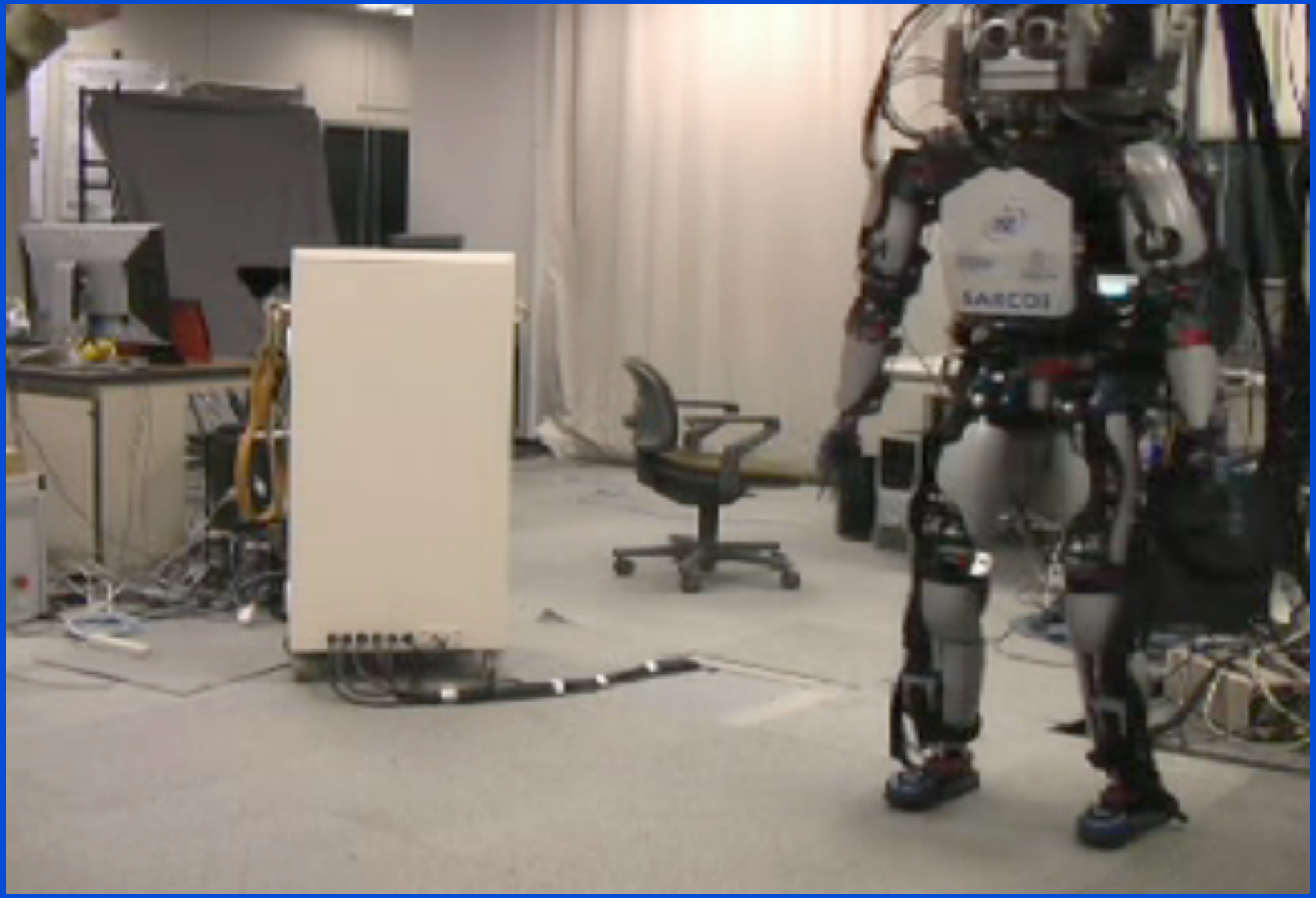
Prediction of Locomotion

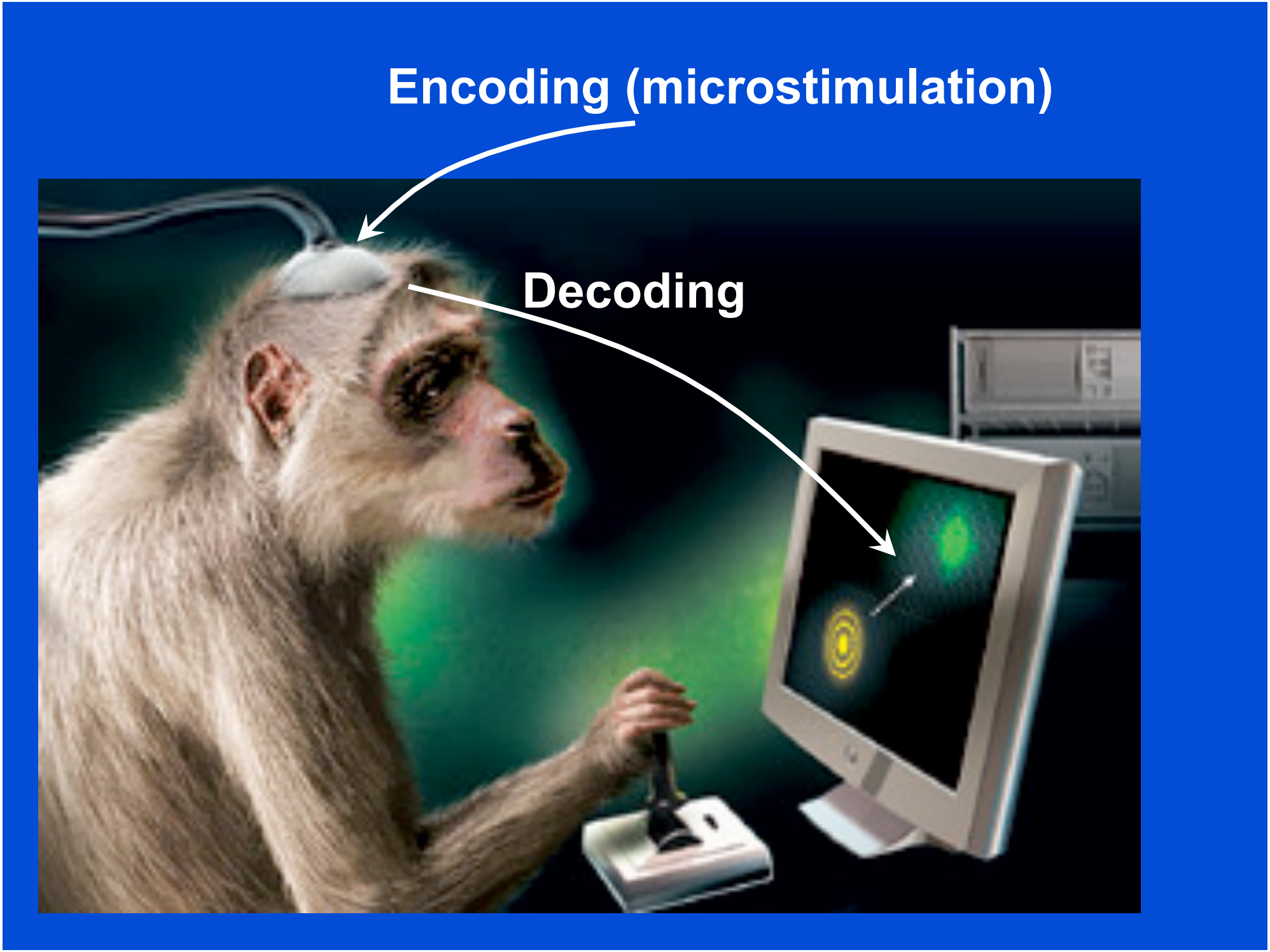


Humanoid Robot at ATR, Kyoto, Japan Driven by Monkey Neural Activity (In Real Time!)

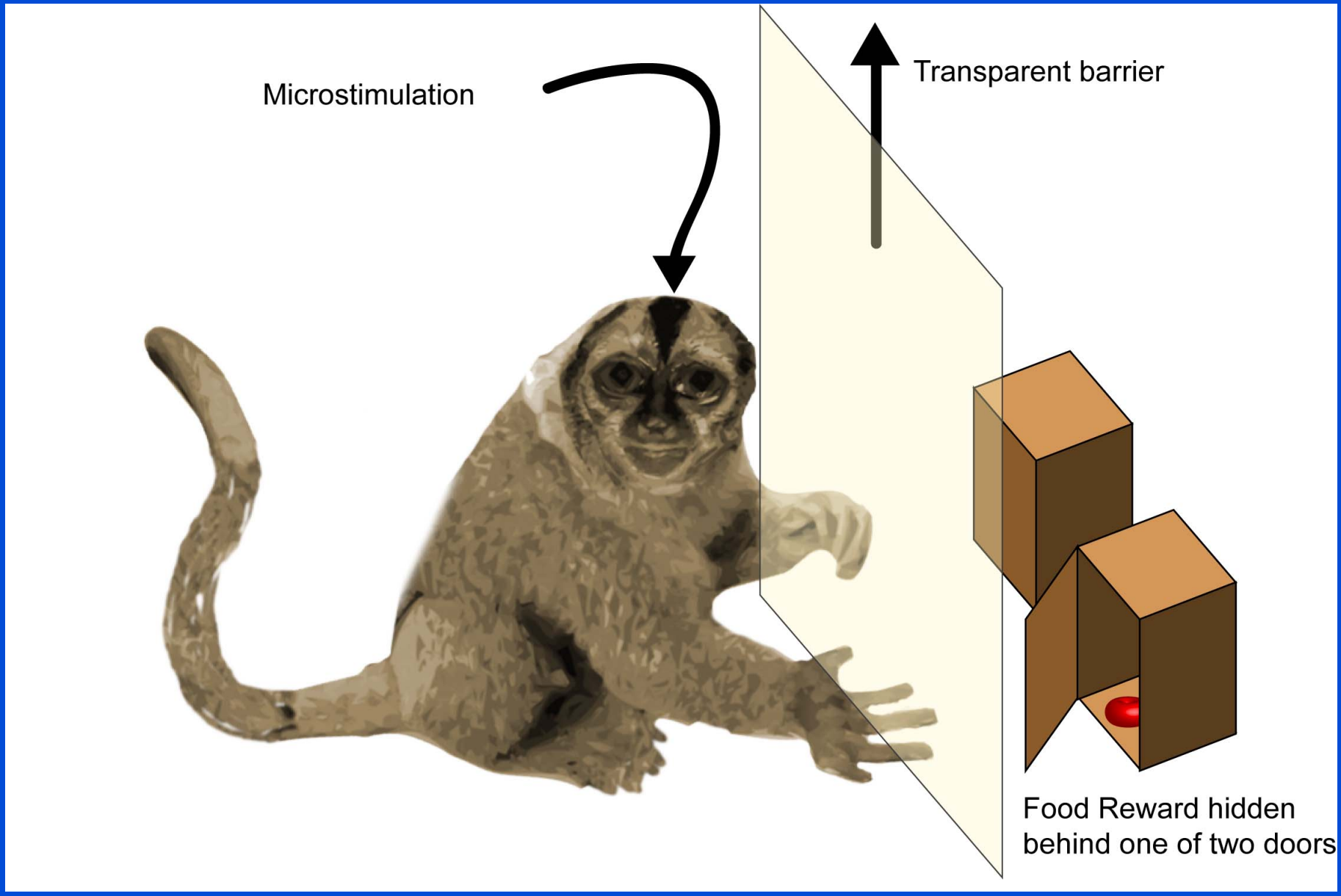


Humanoid Robot at ATR, Kyoto, Japan Driven by Monkey Neural Activity (In Real Time!)



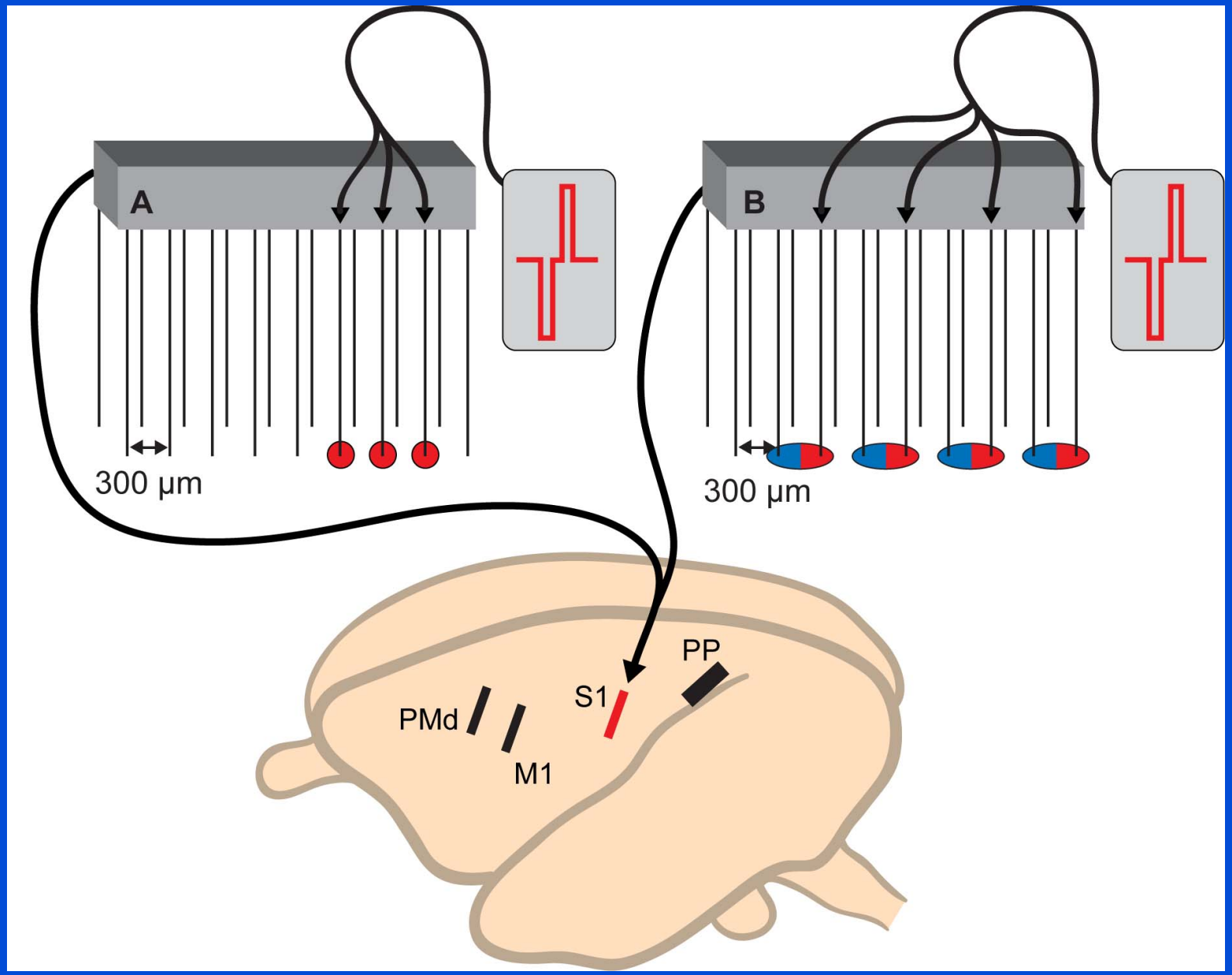

Encoding (microstimulation)
Decoding

Owl monkey reaching experiment



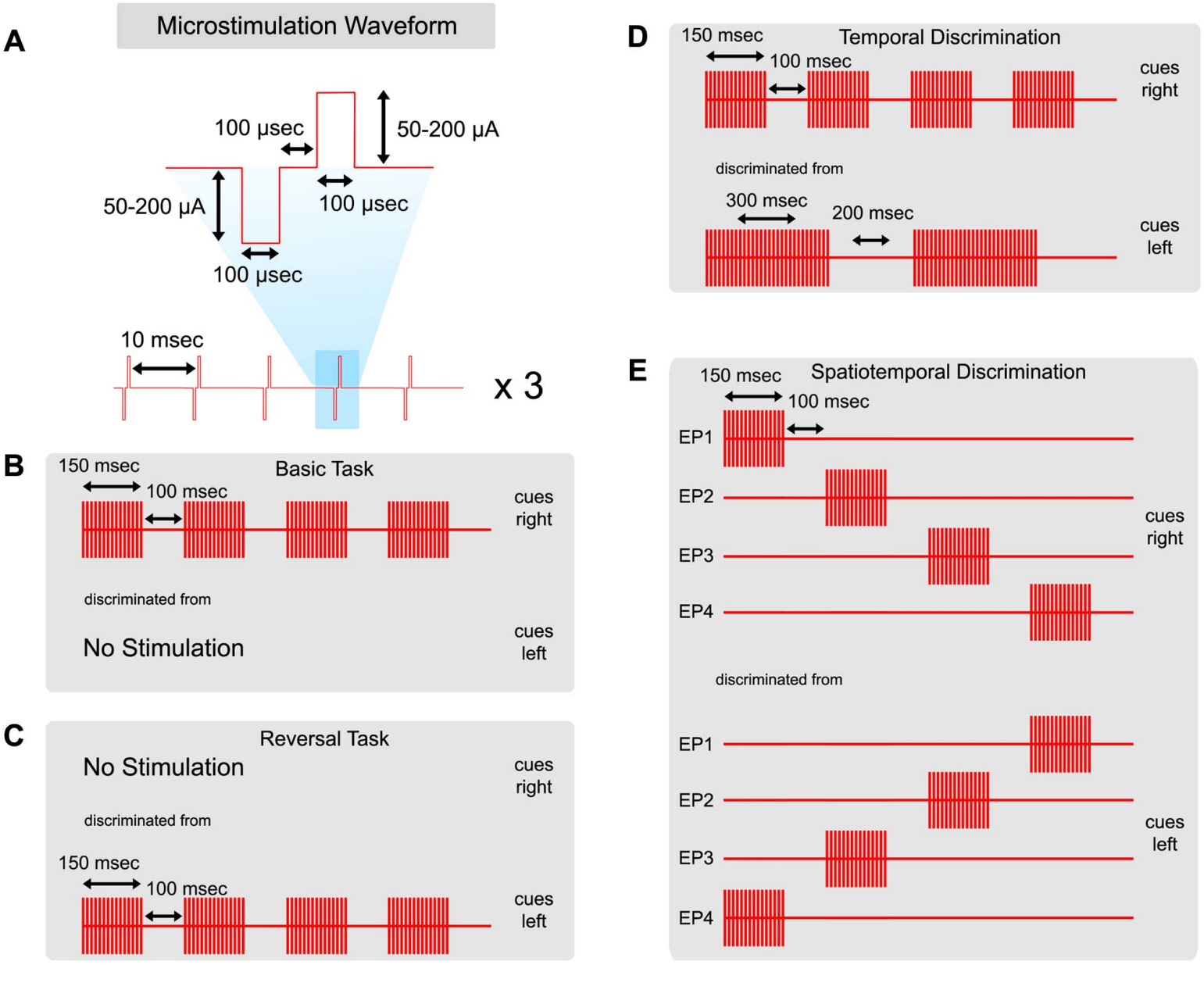
Fitzsimmons et al., 2007

Stimulating electrodes



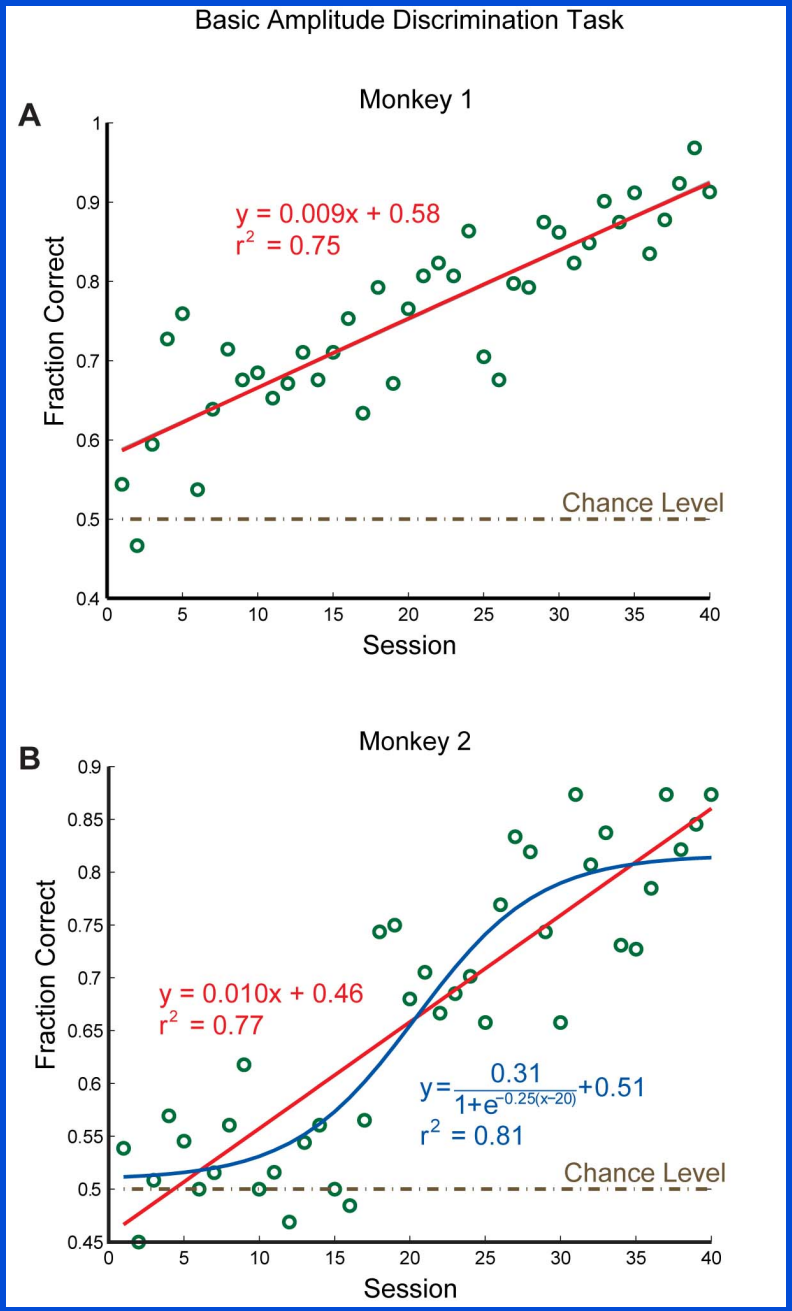
Fitzsimmons et al., 2007

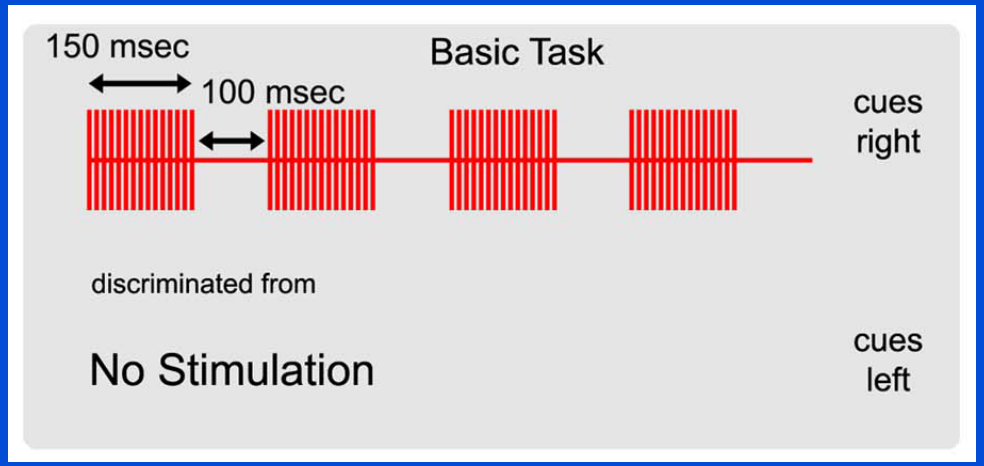
Microstimulation patterns



Fitzsimmons et al., 2007

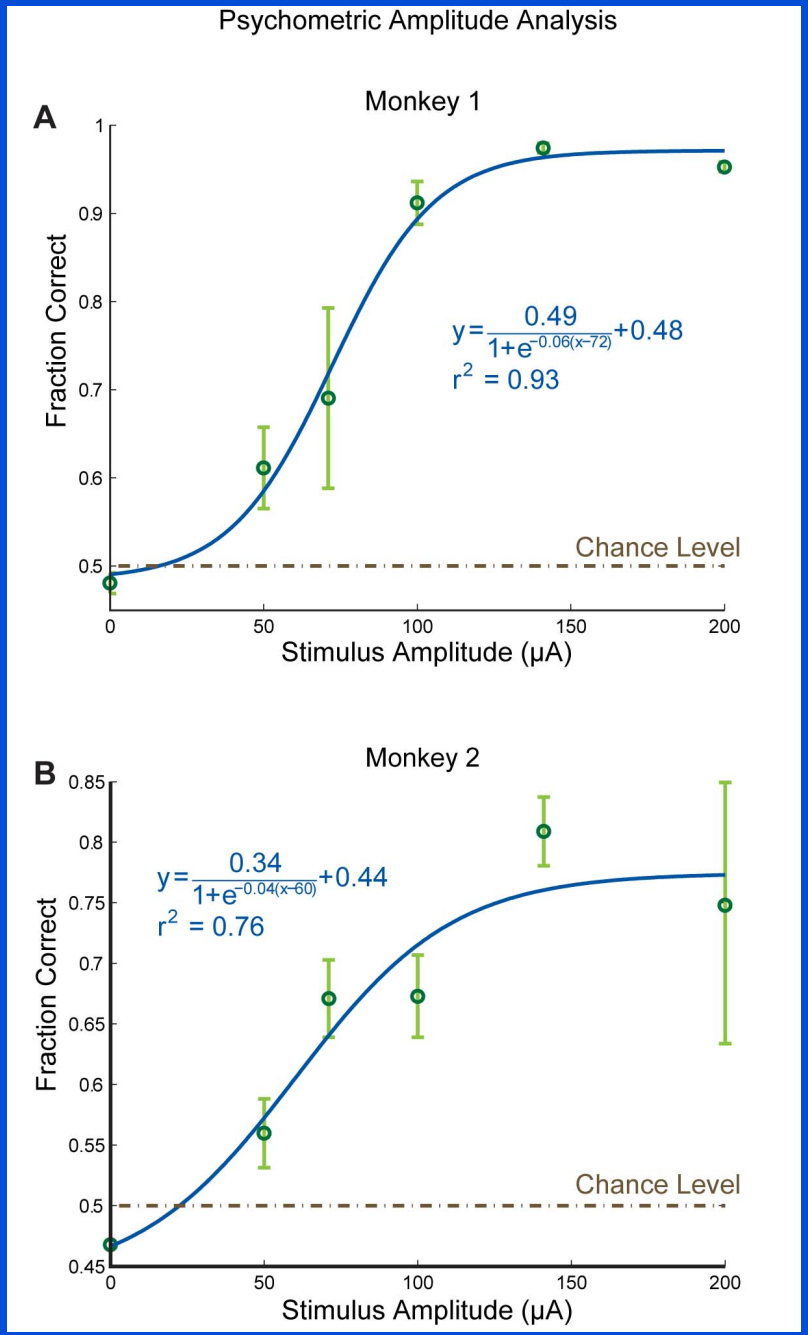
Initial training





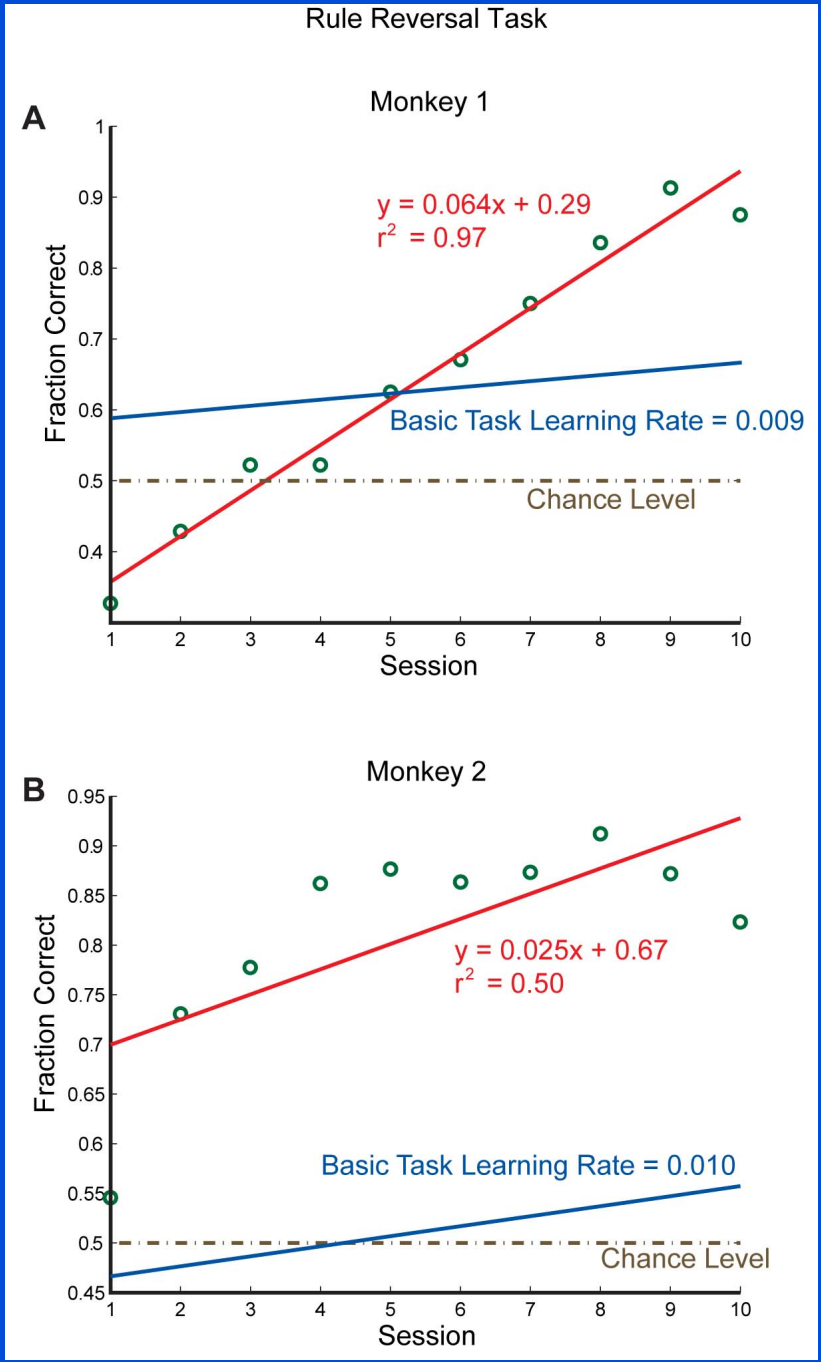
Fitzsimmons et al., 2007

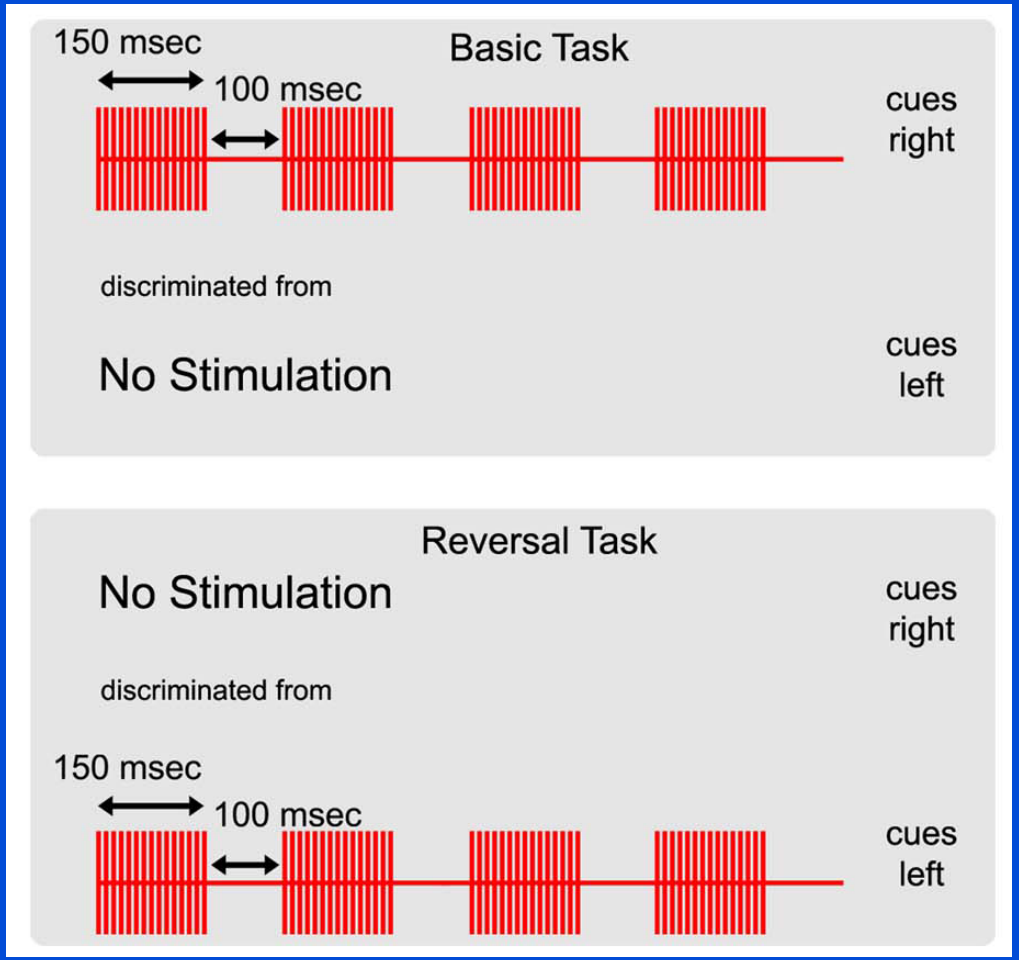
Psychometric curve



Fitzsimmons et al., 2007

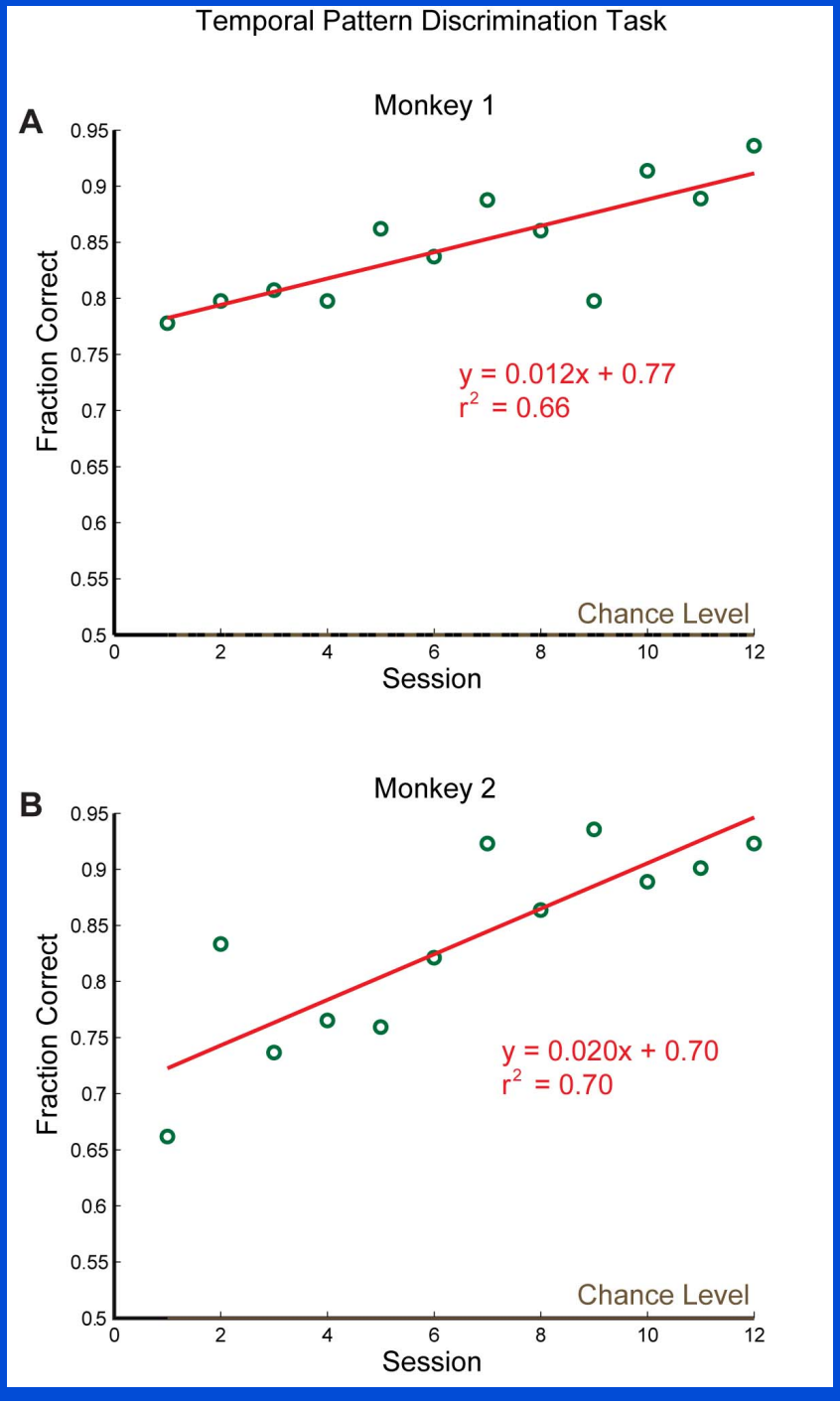
Reversal task

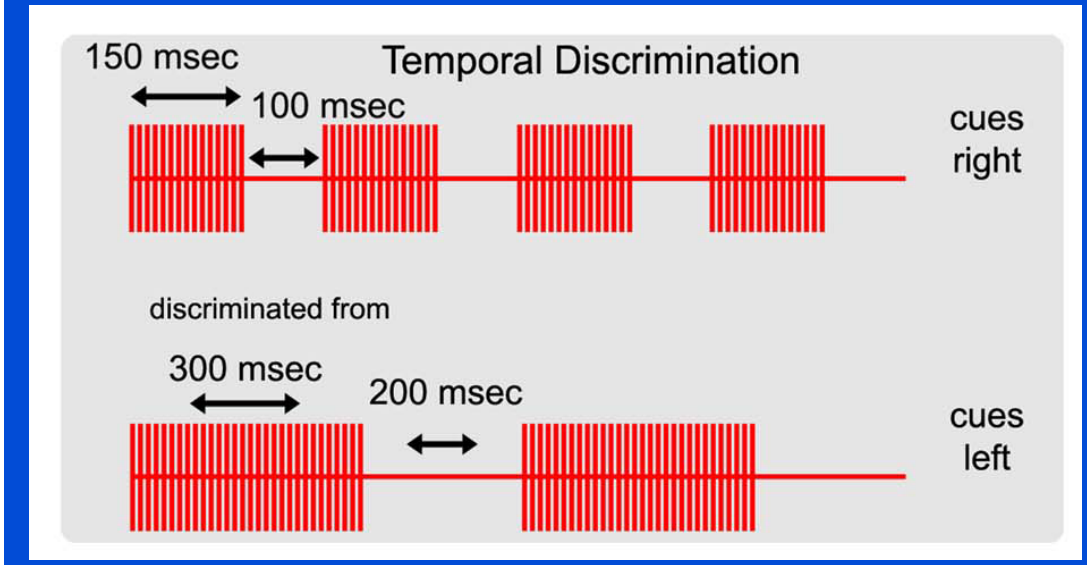




Fitzsimmons et al., 2007

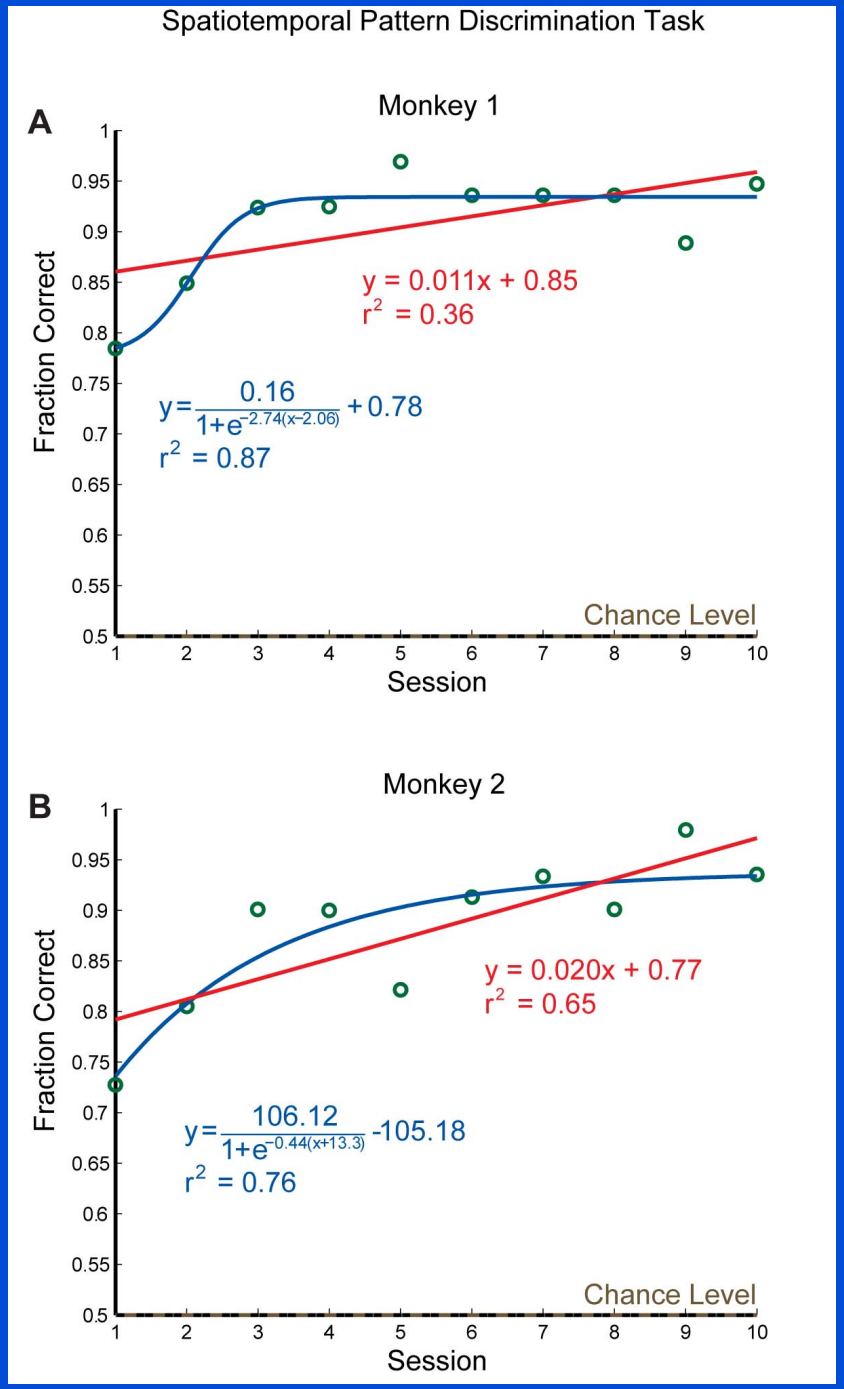
Discrimination of temporal patterns

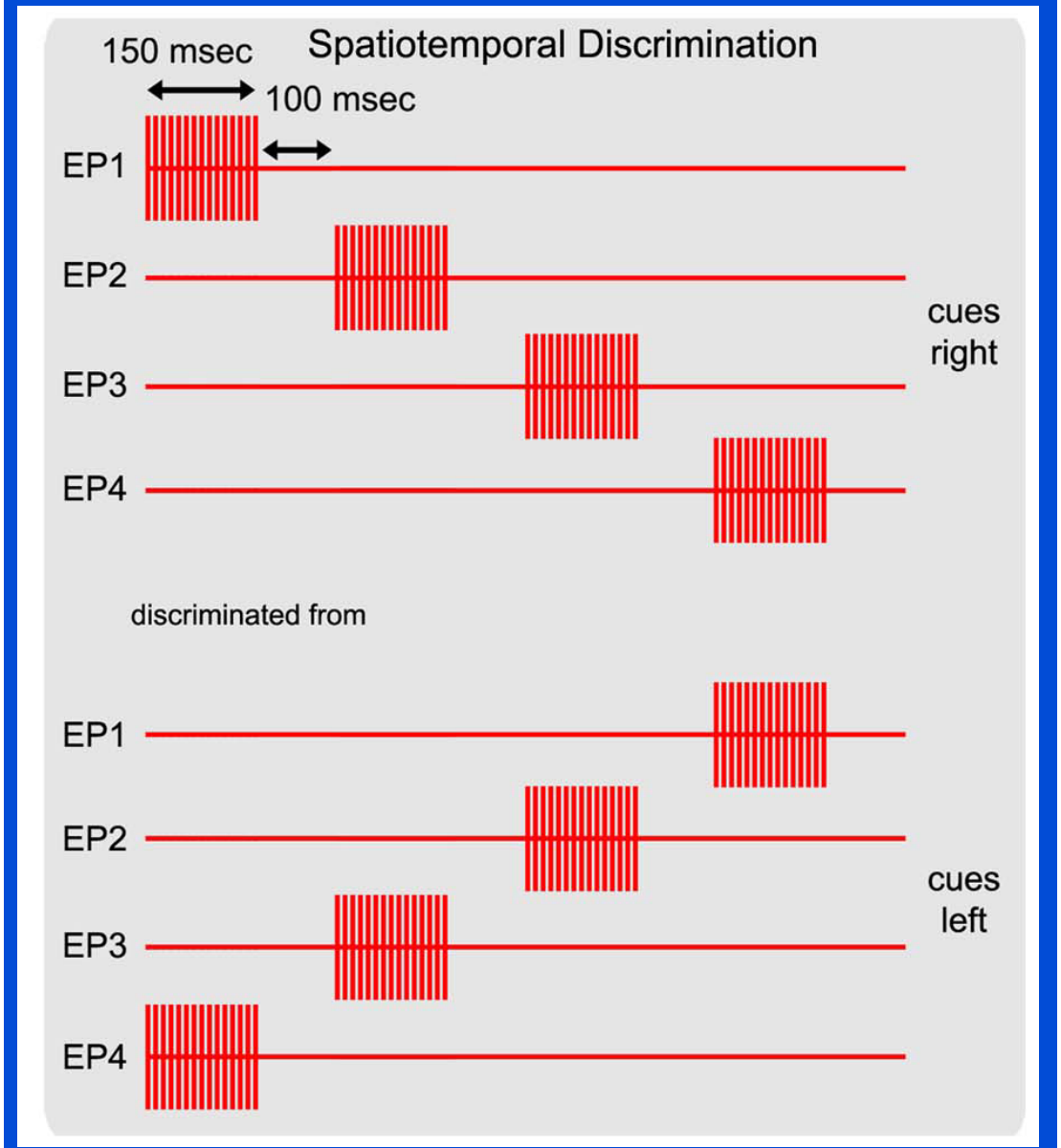




Fitzsimmons et al., 2007

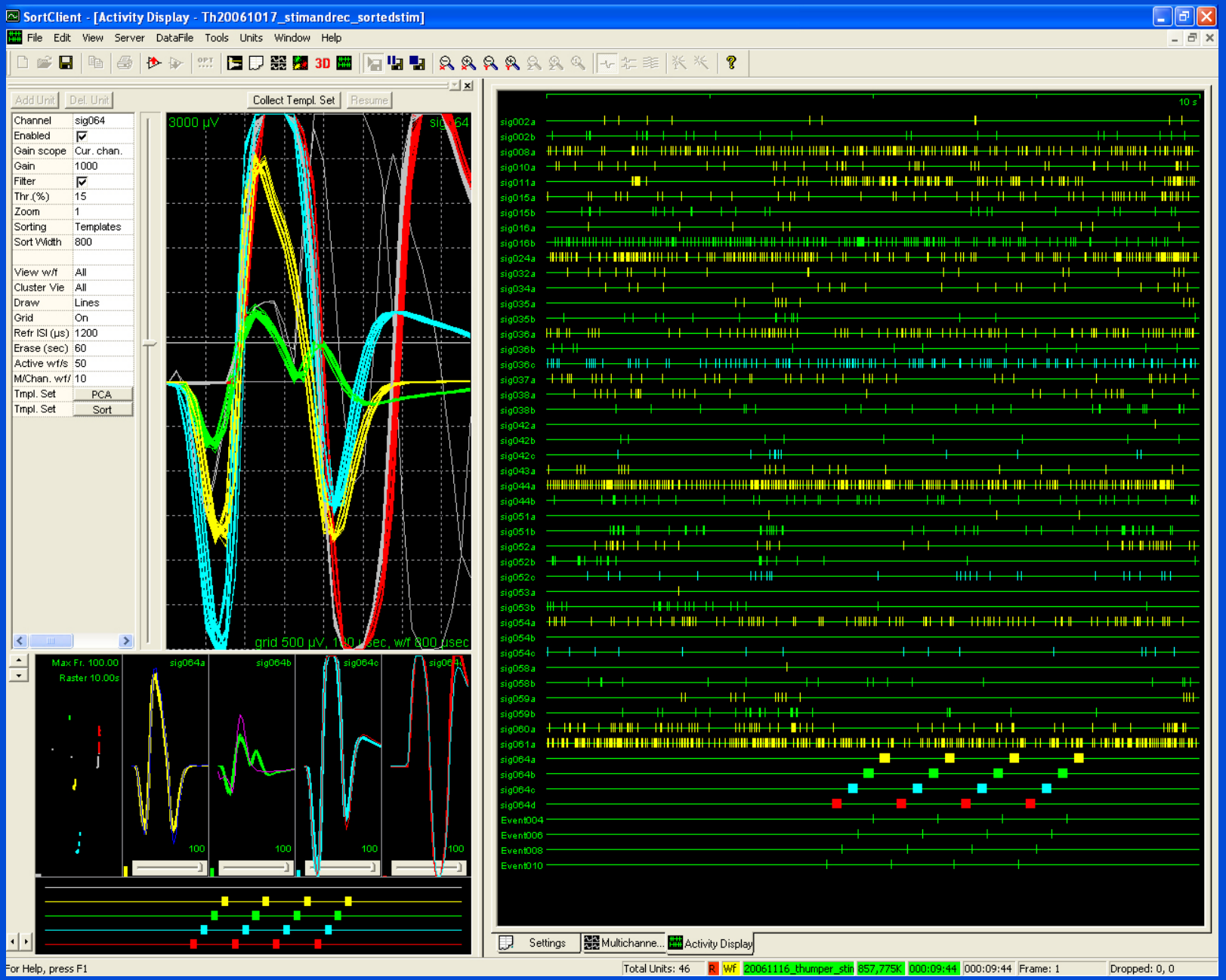
Discrimination of spatiotemporal patterns





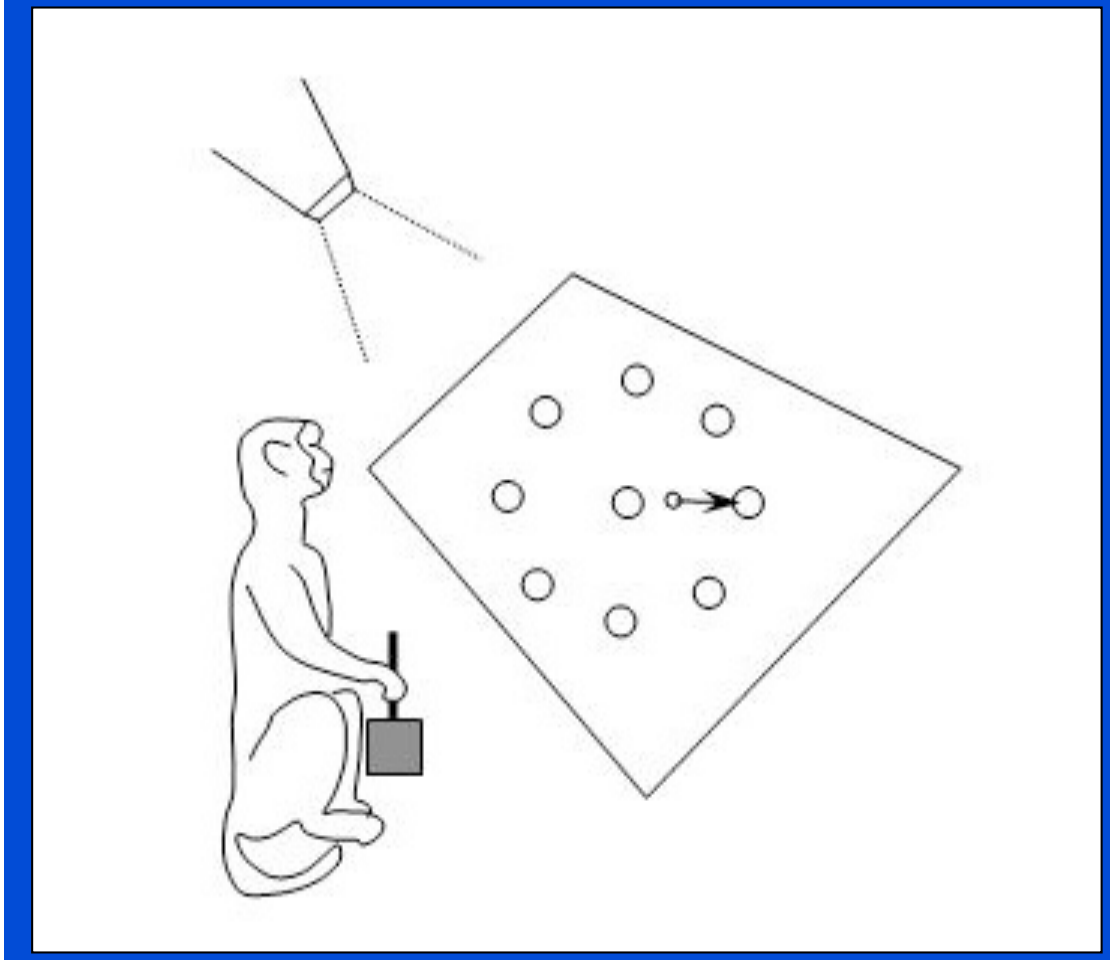
Ftizsimmons et al., 2007

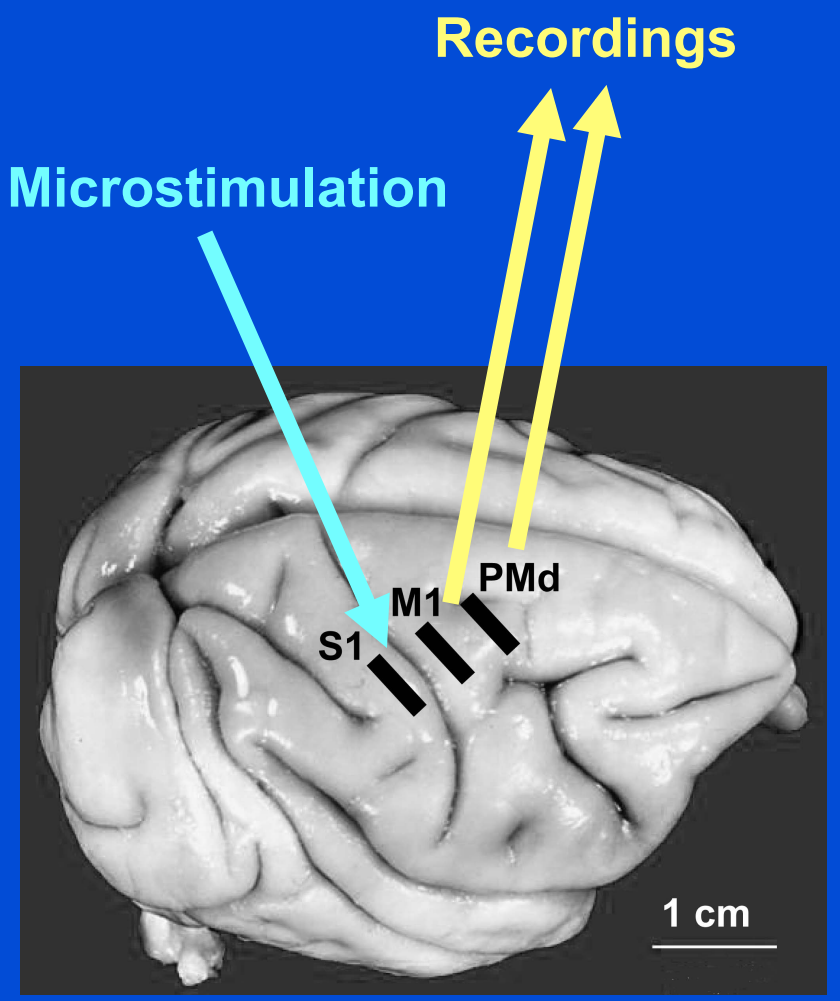
Recordings during microstimulation



Fitzsimmons et al., 2007

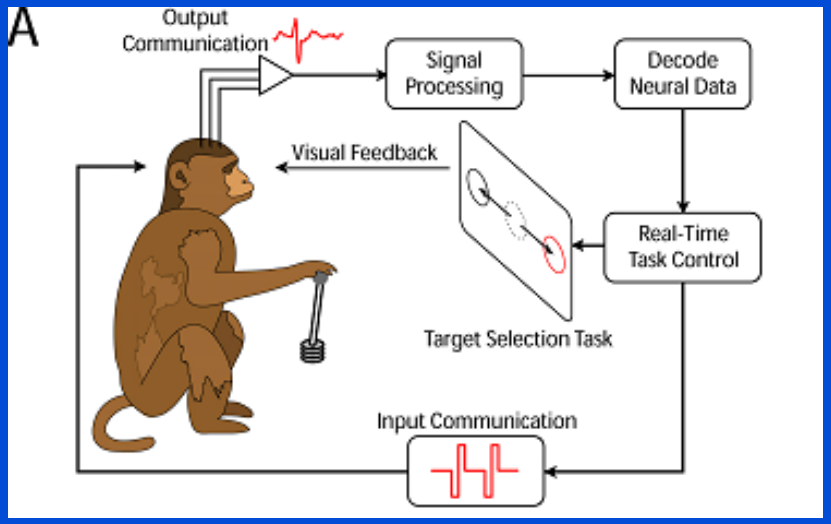
Microstimulation in Rhesus Monkeys

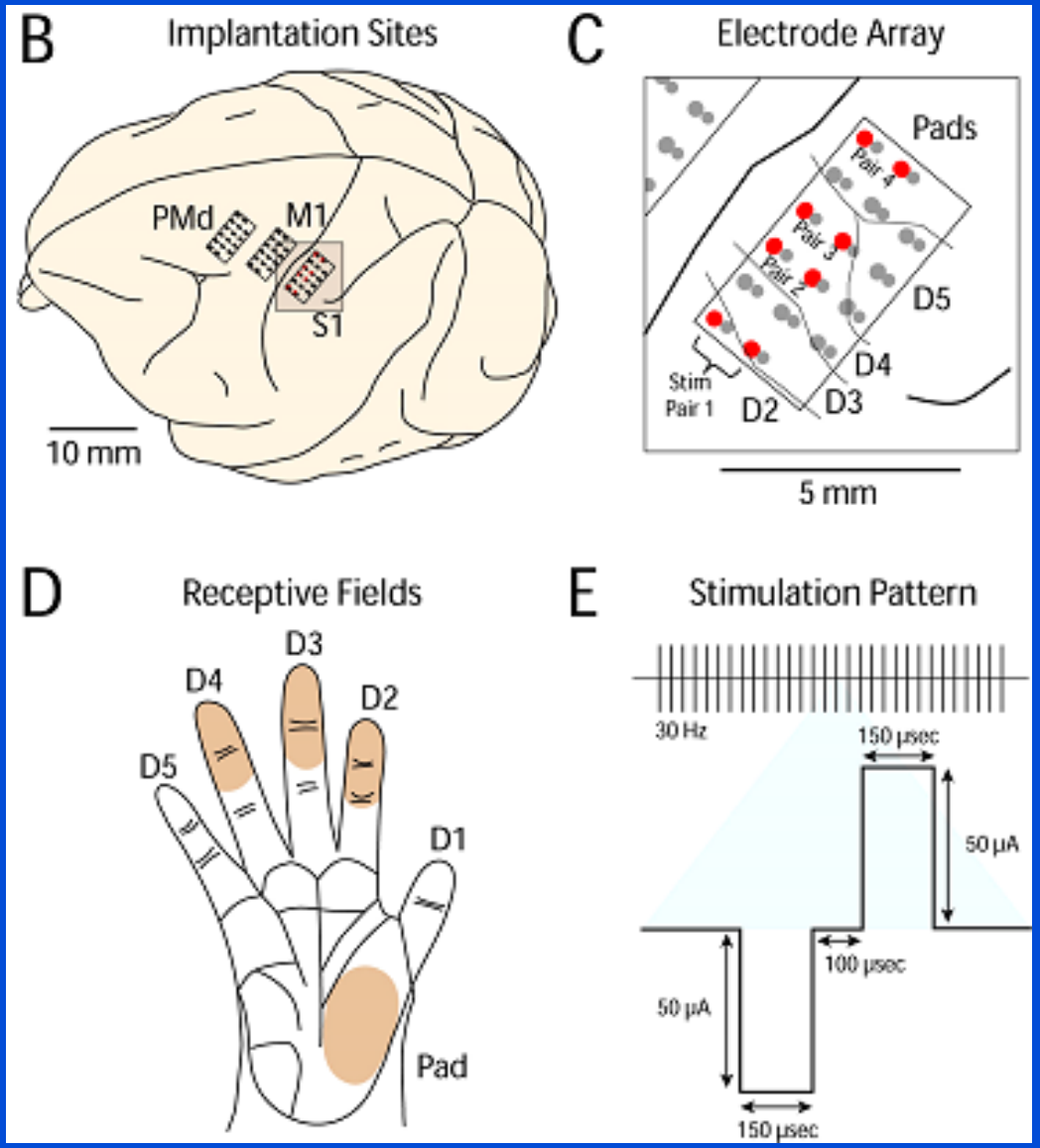




O'Doherty et al., unpublished

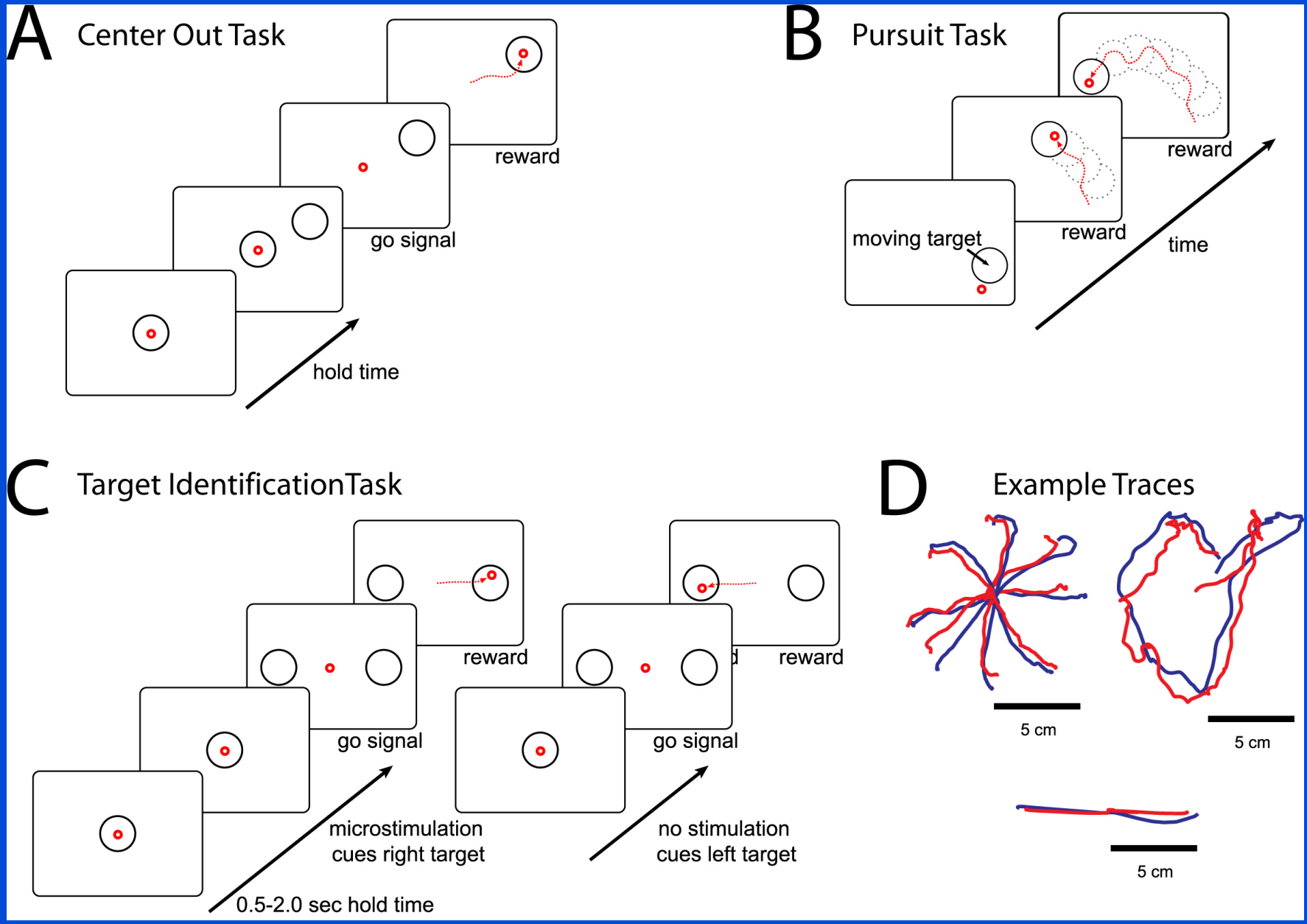
Microstimulation in Rhesus Monkeys





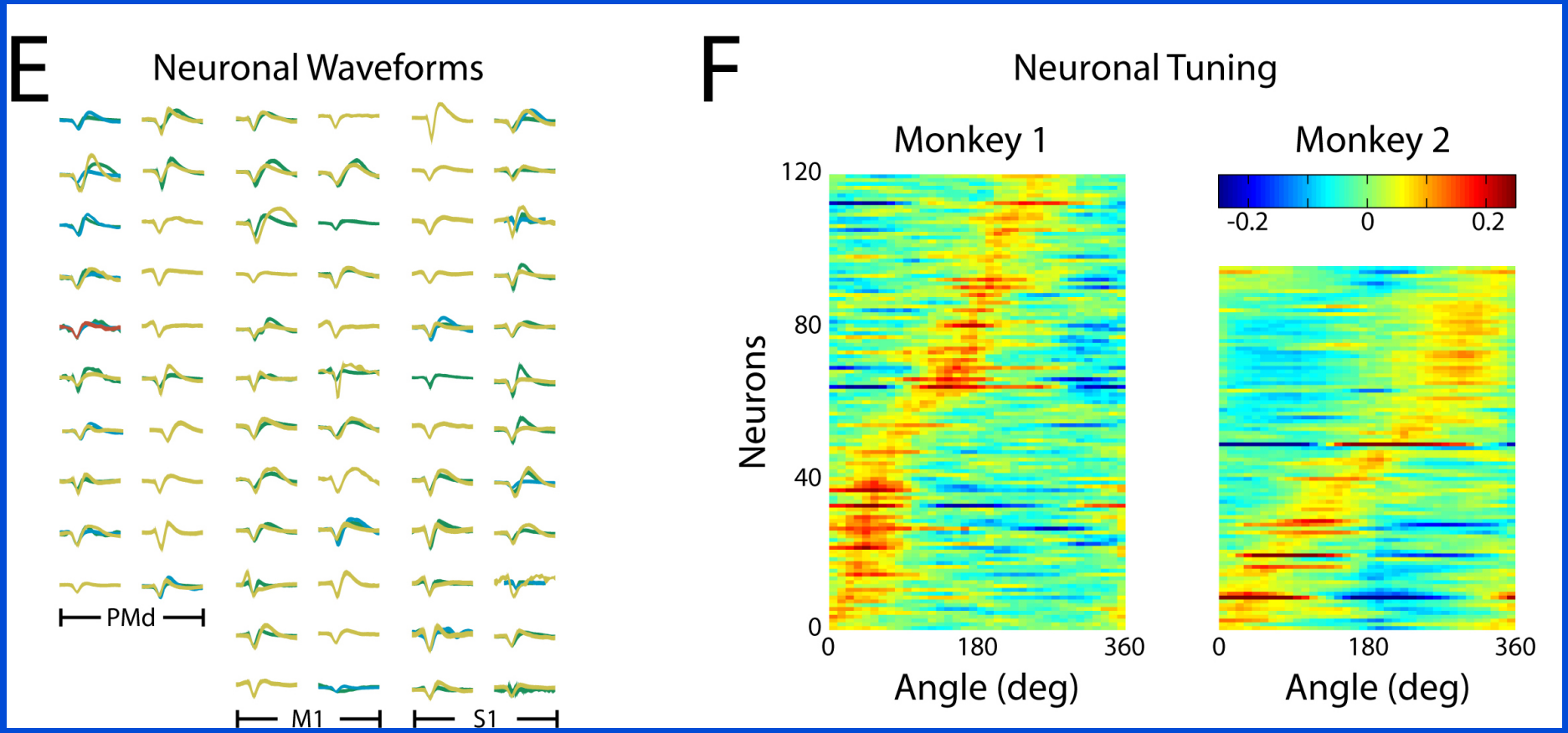
O'Doherty et al., unpublished

Microstimulation in Rhesus Monkeys



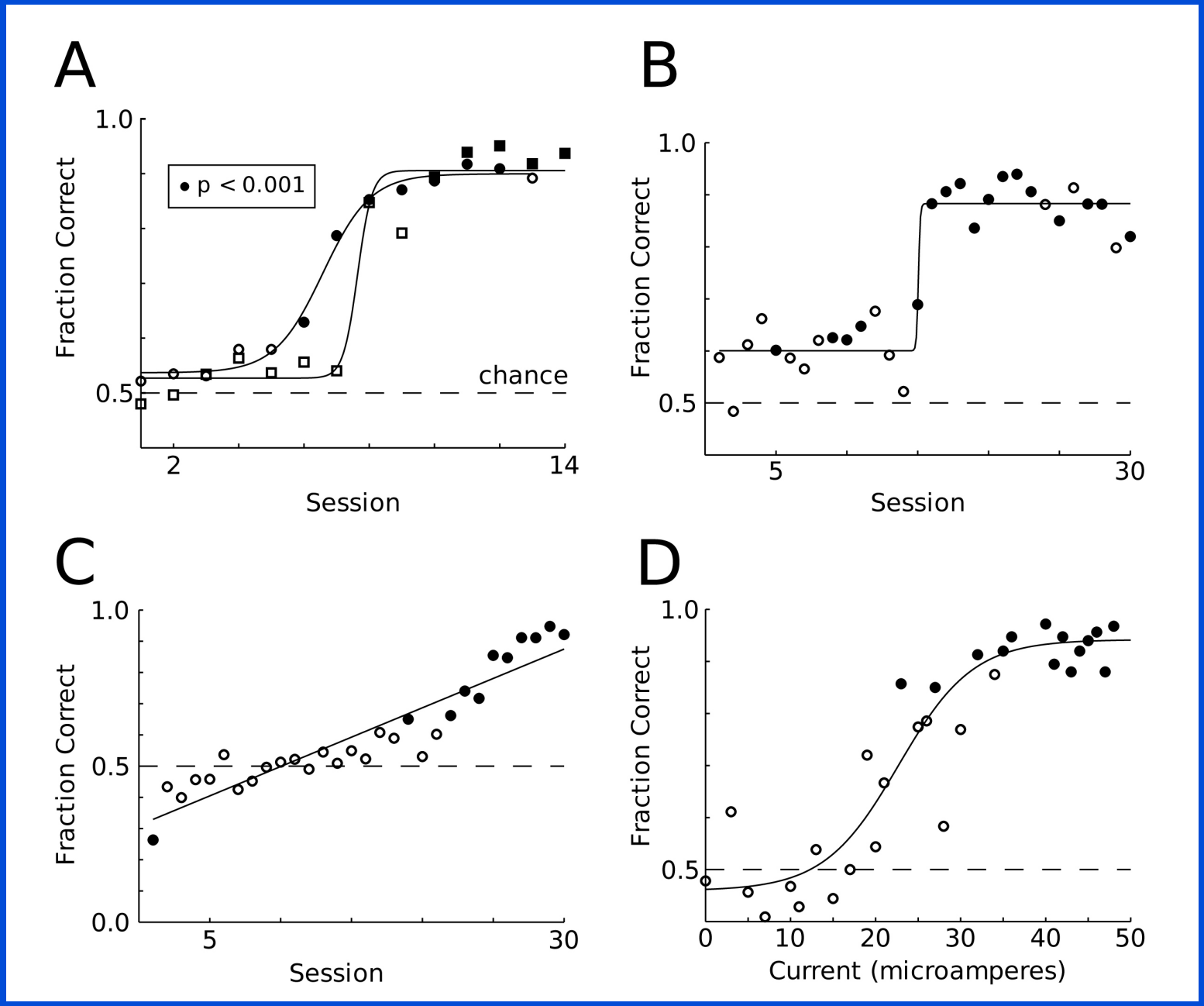
O'Doherty et al., unpublished

Microstimulation in Rhesus Monkeys



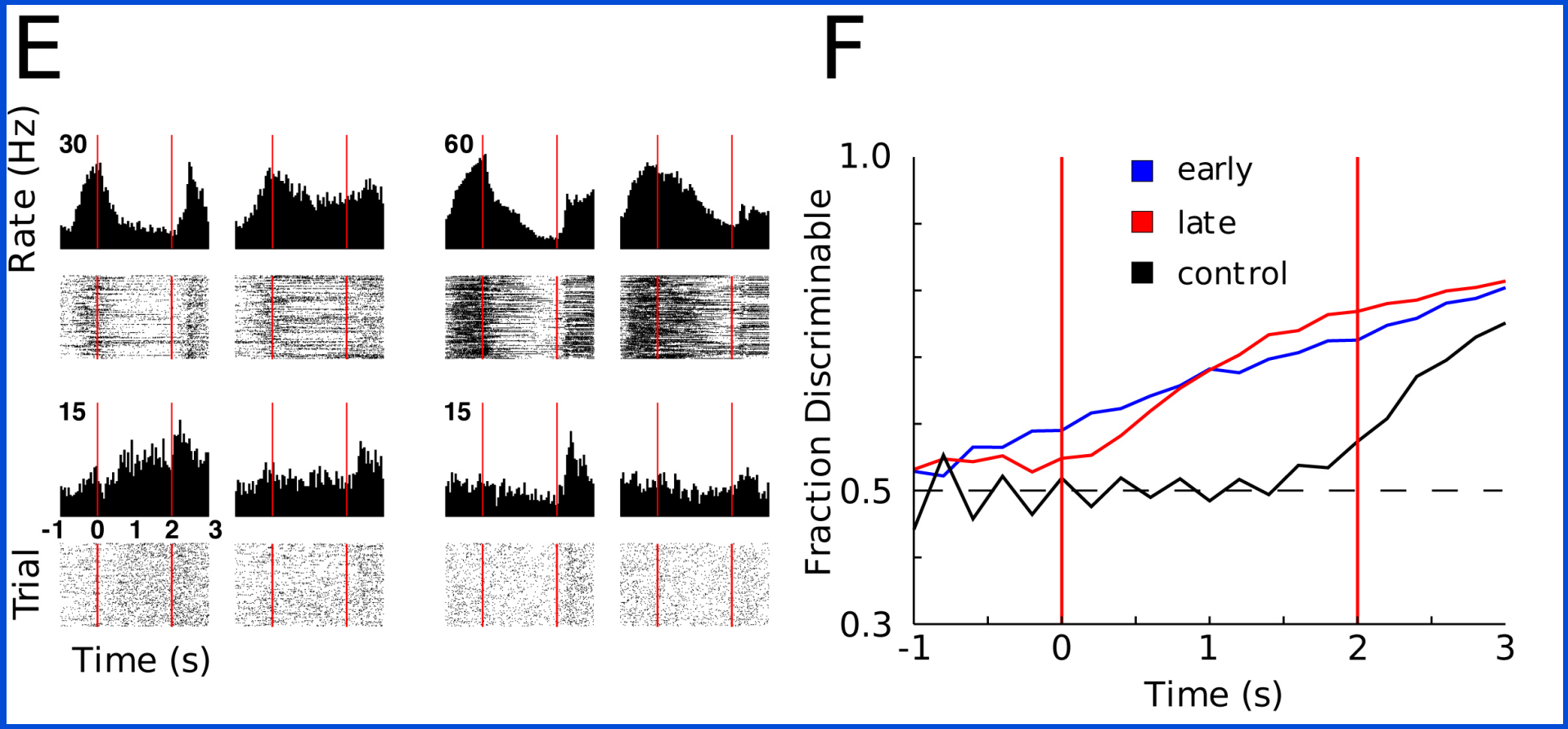
O'Doherty et al., unpublished

Learning with Vibratory Cue



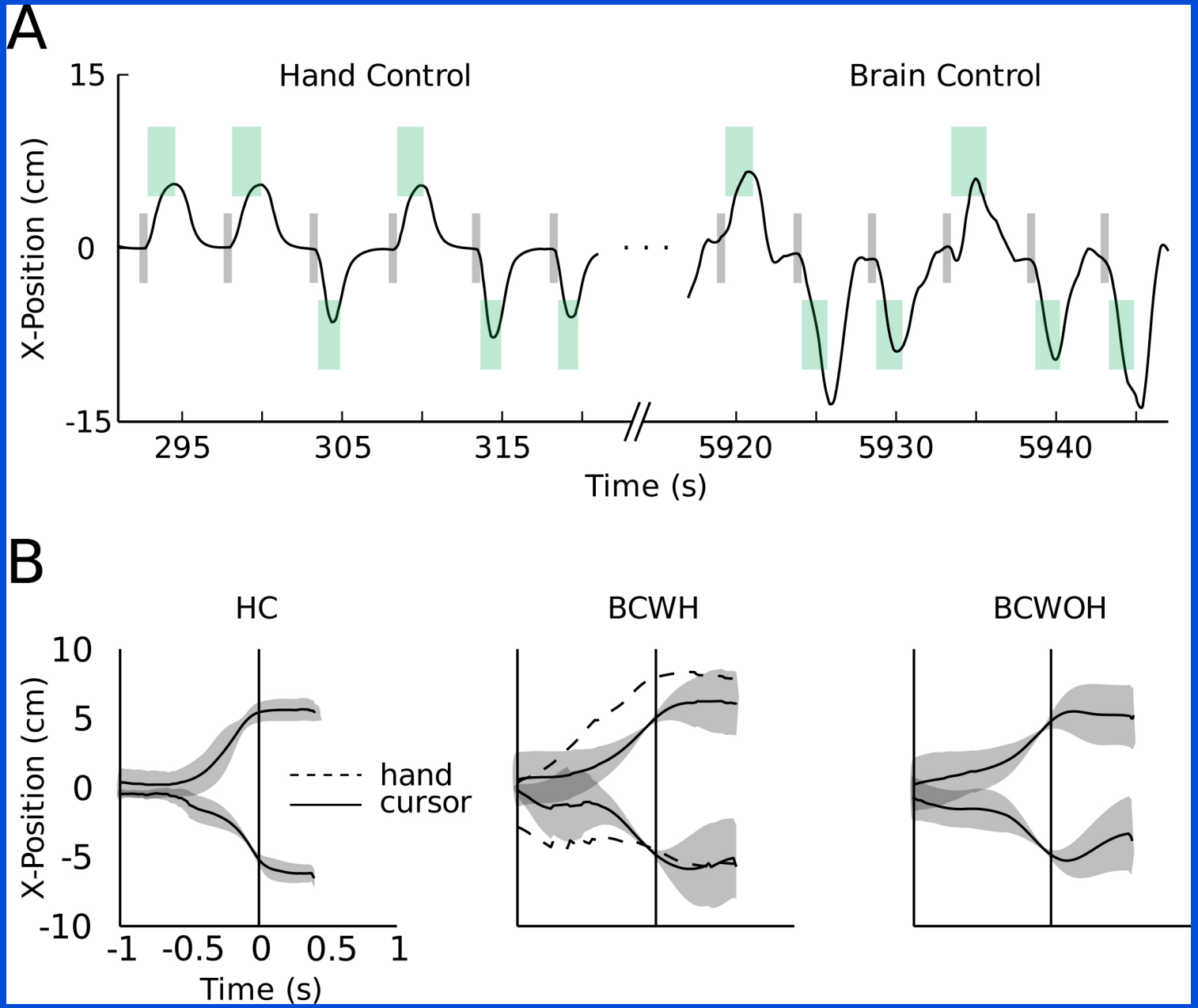
O'Doherty et al., unpublished

Learning with Microstimulation Cue



O'Doherty et al., unpublished

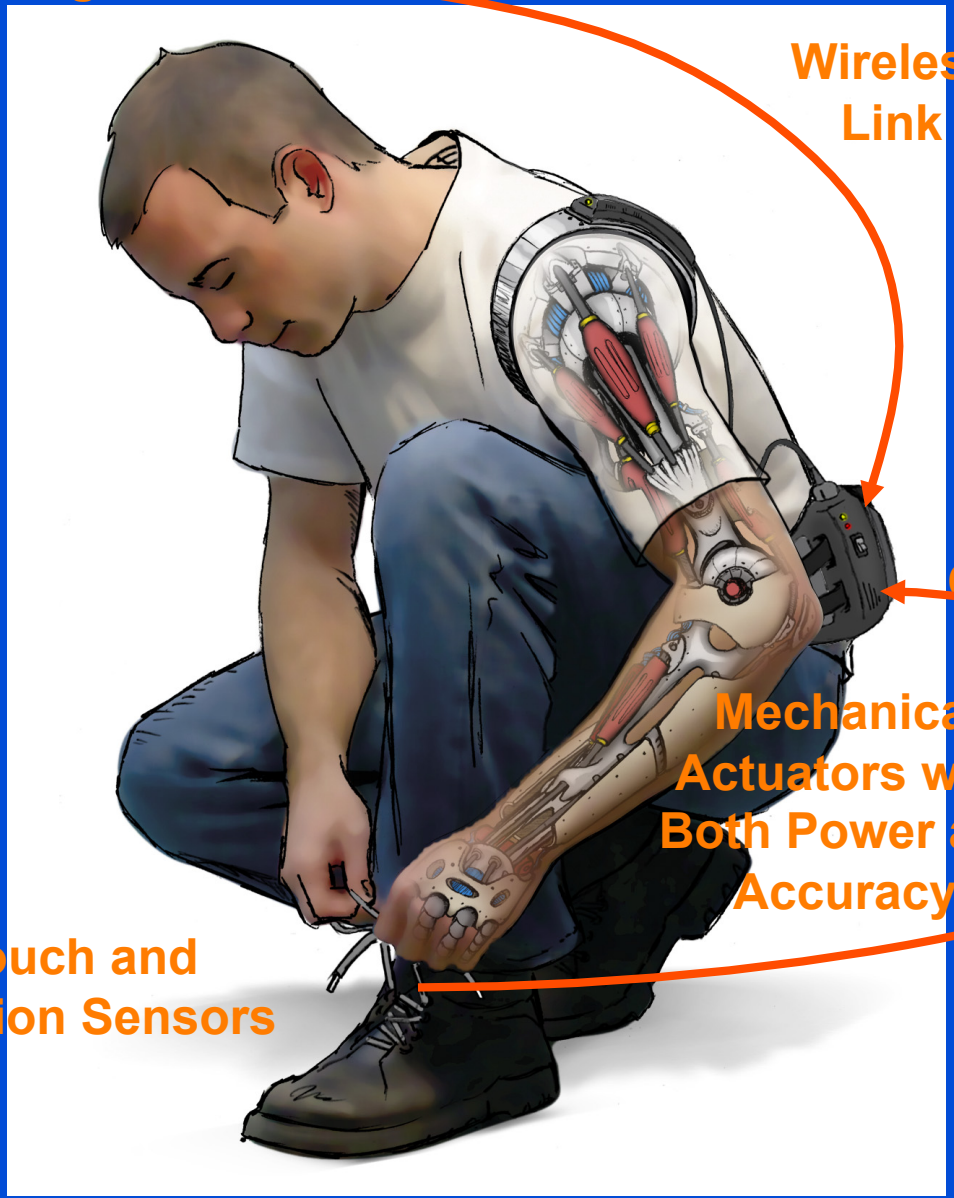
Bidirectional BMI



O'Doherty et al., unpublished

Perspectives

Fully Implantable Multichannel Recording/Stimulating Device



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