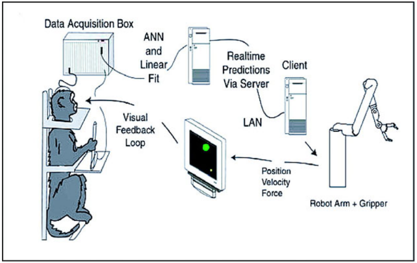
J Neurophysiol 107: 1337–1355, 2012.
First published December 7, 2011; doi:10.1152/jn.00781.2011.

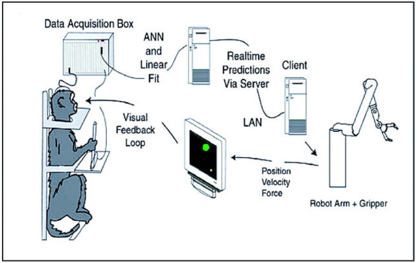
Decoding 3D reach and grasp from hybrid signals in motor and premotor cortices: spikes, multiunit activity, and local field potentials

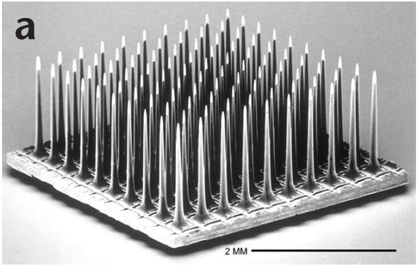
Arjun K. Bansal,[1] Wilson Truccolo,[1,2,3,4] Carlos E. Vargas-Irwin,[1] and John P. Donoghue[1,2,4]

Multi-electrode recordings for BCIs

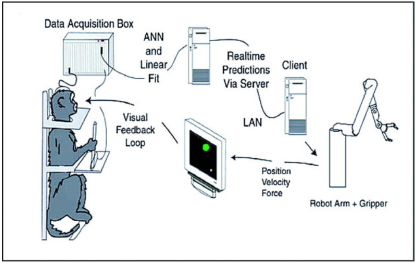


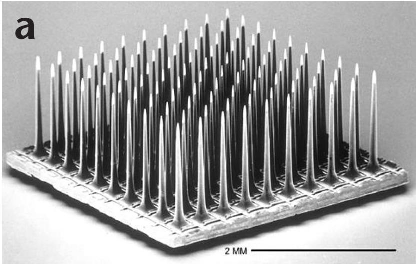
Multi-electrode recordings for BCIs

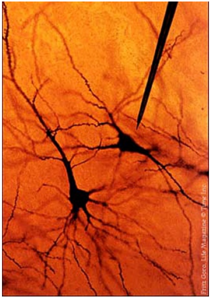




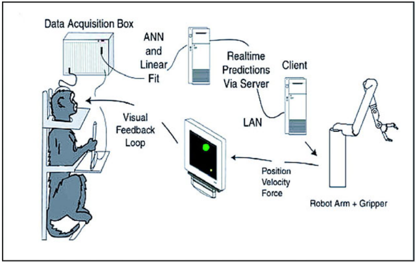
Multi-electrode recordings for BCIs

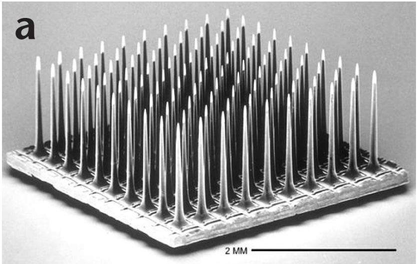


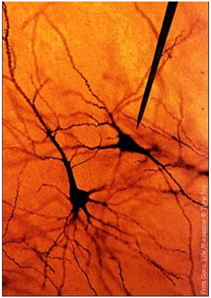


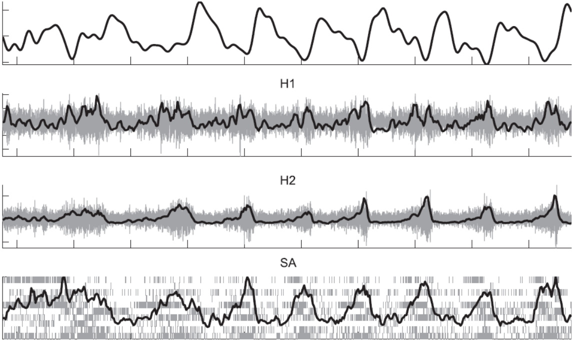


Multi-electrode recordings for BCIs



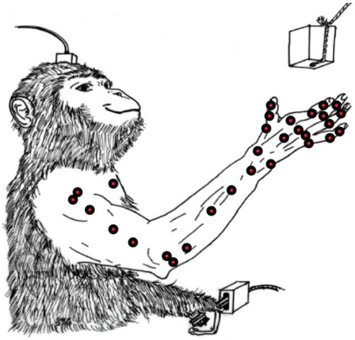






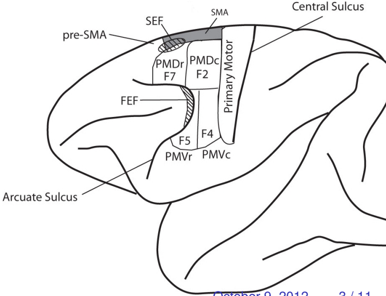
Experimental setup

- 2 macaque monkeys
- arrays in M1 and PMv
- unconstrained 3d reach & grasp movements
- track 8 kinematic variables: wrist position & velocity and grasp aperture
- open loop decoding; allows for testing numerous decoders
- but $\neq$ closed loop



Questions

- which signals allow for good decoding? LFP vs. spiking activity (SA)
- differences between M1 and PMv esp wrt reach and grasp decoding?



Extracellular recordings

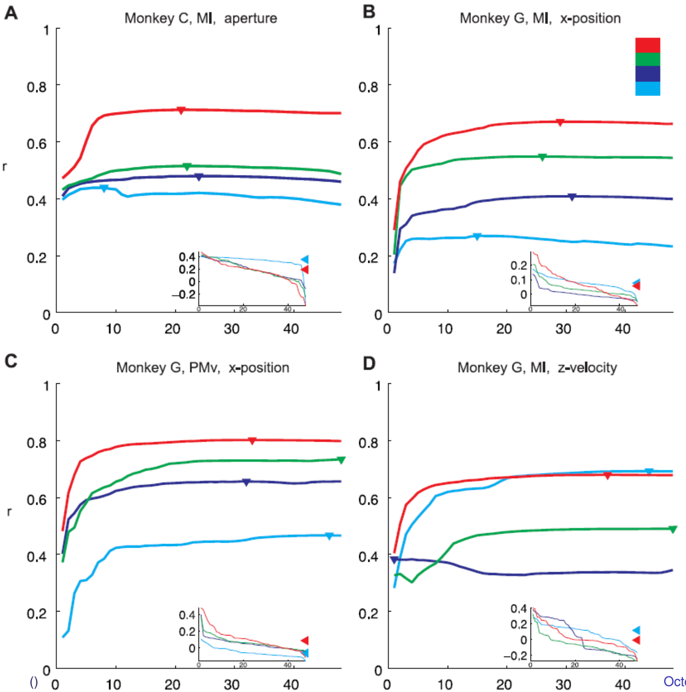
- LFP: 3 frequency bands
  - LF: $0.5 - 2\,\mathrm{Hz}$
  - H1: $100 - 200\,\mathrm{Hz}$
  - H2: $200 - 400\,\mathrm{Hz}$
- previous study found γ to give inferior performance
- Spike activity: extract spike times of both well-isolated units (esp monkey G, session 2) and multi-unit activity with spike sorting

	MI	PMv
Monkey C, session 1, 12/12/07	136	99
Monkey C, session 2, 3/19/08	115	142
Monkey G, session 1, 7/2/08	76	171
Monkey G, session 2, 7/10/08	30	108

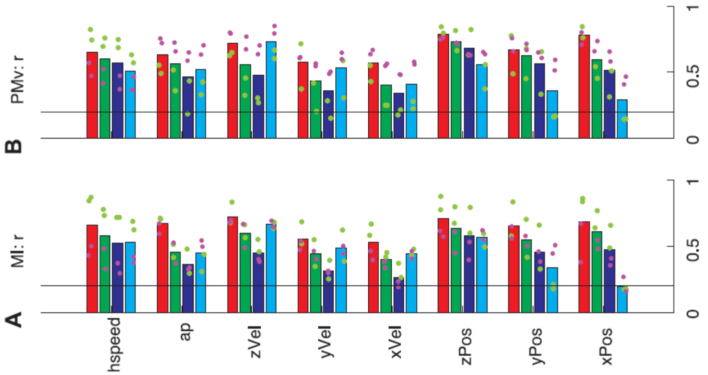
- $50\,\mathrm{ms}$ time steps of kinematic variables, and $150\,\mathrm{ms}$ bins for input signals

Decoder

- decoding with Kalman filters
- cross-validated corr coeff and nRMSE between decoder output and recorded kinematics
- to avoid overfitting they build decoders using greedy input selection:
  - given *n* inputs (= LFP channels / sorted spiking units)
  - for $i \in$ remaining inputs: add input *i* and train decoder
  - add input i^* that increased training performance the most
  - report max performance over # inputs on test data
- results are robust wrt to binning and decoding algorithm (Kalman filter with hidden states, SVR)
- superior to randomly selecting inputs


A
Monkey C, MI, aperture
B
Monkey G, MI, x-position
C
Monkey G, PMv, x-position
D
Monkey G, MI, z-velocity
r
1
0.8
0.6
0.4
0.2
0
10
20
30
40

SA > LFP



SA > LFP

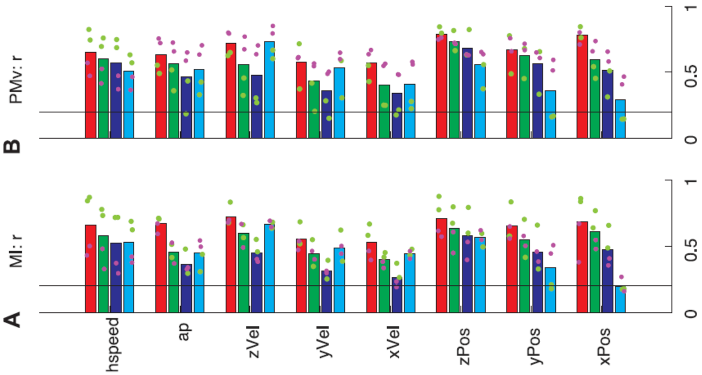
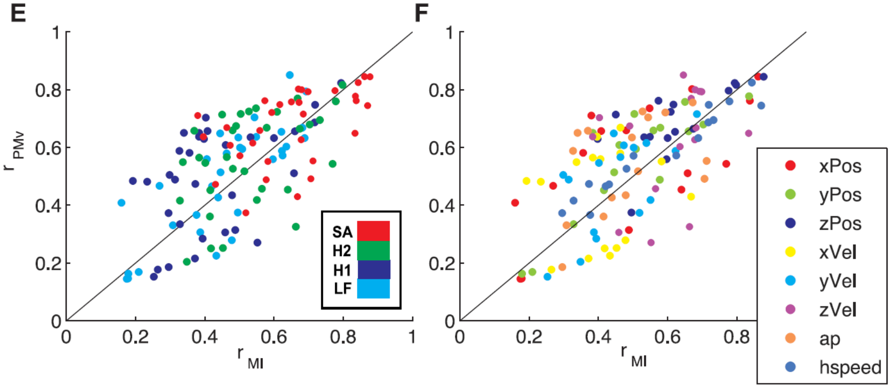


Table 2. *Results for spike and LFP decoding*

Signal/Comparison	1. Mean r (all parameters)	2. Mean r (x, y, z velocity)	3. Mean r (position parameters)	4. Mean nRMSE (all parameters)
Statistical test or note	Mean sig. diff. (all pairs)	Mean sig. diff. (all pairs)	Mean sig. diff. (all pairs)	Mean sig. diff. (all pairs)
LF	0.47 ± 0.02 (†H1, H2) (*SA)	0.55 ± 0.03 (*H1) (†H2, SA)	0.38 ± 0.04 (*H1, H2, SA)	0.21 ± 0.04 (†H1, H2) (*SA)
H1	0.46 ± 0.02 (‡H2) (*SA)	0.37 ± 0.03 (†H2) (*SA)	0.55 ± 0.03 (†H2) (*SA)	0.20 ± 0.04 (†H2) (*SA)
H2	0.55 ± 0.02 (*SA)	0.47 ± 0.03 (*SA)	0.62 ± 0.02 (†SA)	0.19 ± 0.03 (‡SA)
Spikes	0.66 ± 0.02	0.61 ± 0.03	0.71 ± 0.03	0.17 ± 0.04
All signals	0.53 ± 0.01	0.50 ± 0.02	0.57 ± 0.02	0.19 ± 0.04

No consistent difference between M1 and PMv



Pooled decoders: performance saturates at better area / signal

Table 3. *Results for multiple-area decoding*

Signal/Comparison	1. Mean *r* (MA, combined areas)	2. Mean RMSE (MA, combined areas)	3. Mean *r* Improvement (using both areas over just the better area)	4. Mean *r* Improvement (using both areas over just the worse area)
Statistical test/notes	Mean sig. diff. (all pairs)	Mean sig. diff. (all pairs)	*t*-Test for mean sig. diff. from zero	*t*-Test for mean sig. diff. from zero
LF	0.54 ± 0.03 (†H1) (‡H2) (*SA)	0.20 ± 0.04 (†H1, H2) (*SA)	0.02 ± 0.02*	0.11 ± 0.07*
H1	0.57 ± 0.02 (†H2) (*SA)	0.19 ± 0.03 (†H2) (*SA)	0.03 ± 0.03*	0.19 ± 0.09*
H2	0.65 ± 0.02 (‡SA)	0.18 ± 0.03 (‡SA)	0.03 ± 0.03*	0.17 ± 0.08*
Spikes	0.74 ± 0.02	0.15 ± 0.03	0.02 ± 0.03*	0.14 ± 0.07*
All signals	0.62 ± 0.01	0.18 ± 0.04	0.03 ± 0.03*	0.15 ± 0.08*

Pooled decoders: performance saturates at better area / signal

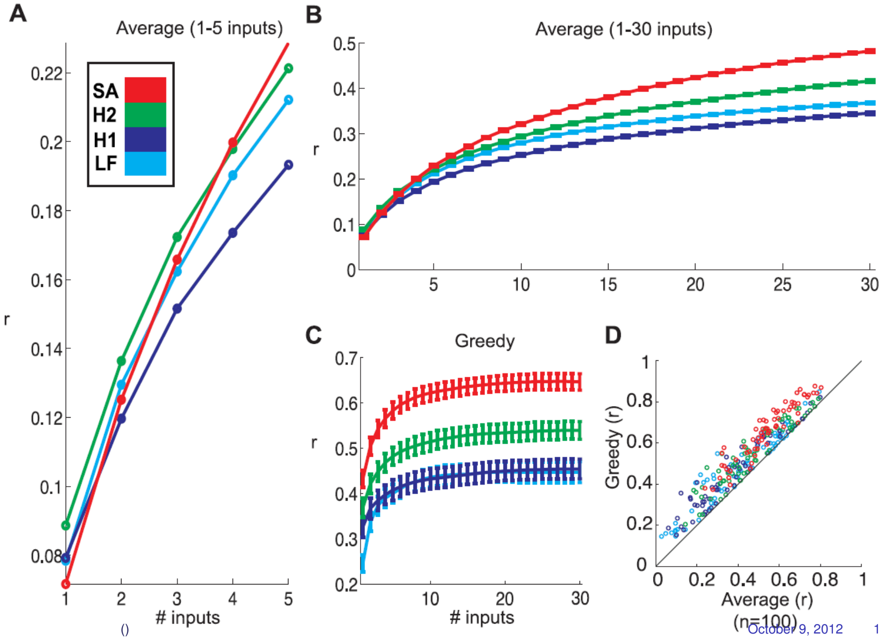
Table 3. *Results for multiple-area decoding*

Signal/Comparison	1. Mean *r* (MA, combined areas)	2. Mean RMSE (MA, combined areas)	3. Mean *r* Improvement (using both areas over just the better area)	4. Mean *r* Improvement (using both areas over just the worse area)
Statistical test/notes	Mean sig. diff. (all pairs)	Mean sig. diff. (all pairs)	*t*-Test for mean sig. diff. from zero	*t*-Test for mean sig. diff. from zero
LF	0.54 ± 0.03 (†H1) (‡H2) (*SA)	0.20 ± 0.04 (†H1, H2) (*SA)	0.02 ± 0.02*	0.11 ± 0.07*
H1	0.57 ± 0.02 (†H2) (*SA)	0.19 ± 0.03 (†H2) (*SA)	0.03 ± 0.03*	0.19 ± 0.09*
H2	0.65 ± 0.02 (‡SA)	0.18 ± 0.03 (‡SA)	0.03 ± 0.03*	0.17 ± 0.08*
Spikes	0.74 ± 0.02	0.15 ± 0.03	0.02 ± 0.03*	0.14 ± 0.07*
All signals	0.62 ± 0.01	0.18 ± 0.04	0.03 ± 0.03*	0.15 ± 0.08*

Table 4. *Results for multiband LFP and hybrid signal decoding*

Signal/Comparison	1. Mean *r* Improvement (using all LFP bands vs. just 1)	2. Mean *r* Improvement [using all LFP bands vs. just 1 (position)]	3. Mean *r* Improvement [using all LFP bands vs. just 1 (velocity)]	4. Mean Fraction of Inputs of Each Type in *mb*-LFP Decoding	5. Mean *r* Improvement (using all signals vs. just 1 signal)
Statistical test/notes	*t*-Test for mean sig. diff. from zero	*t*-Test for mean sig. diff. from zero	*t*-Test for mean sig. diff. from zero	Mean sig. diff. (all pairs)	*t*-Test for mean sig. diff. from zero
LF	0.16 ± 0.17*	0.31 ± 0.18*	0.04 ± 0.06*	0.22 ± 0.03 (†H1) (*H2)	0.22 ± 0.18*
H1	0.13 ± 0.08*	0.09 ± 0.05*	0.19 ± 0.07*	0.30 ± 0.02 (*H2)	0.19 ± 0.10*
H2	0.05 ± 0.05*	0.03 ± 0.02*	0.10 ± 0.04*	0.48 ± 0.02	0.12 ± 0.07*
Spikes					0.02 ± 0.03*
All signals	0.11 ± 0.12*	0.14 ± 0.16*	0.11 ± 0.09*		0.14 ± 0.13*
					0.02 ± 0.02 (compared to best)

For few units and average selection: LFP >≈ SA



Summary

- decoding from SA > decoding from LFP bands
  given enough isolated unit (>16)
- information in different signals & anatomical locations (M1, PMv) is mostly redundant
- no consistent difference of decoding reach / grasp movements from M1 / PMv