Motor cortex signals for each arm are mixed across hemispheres and neurons yet partitioned within the population response

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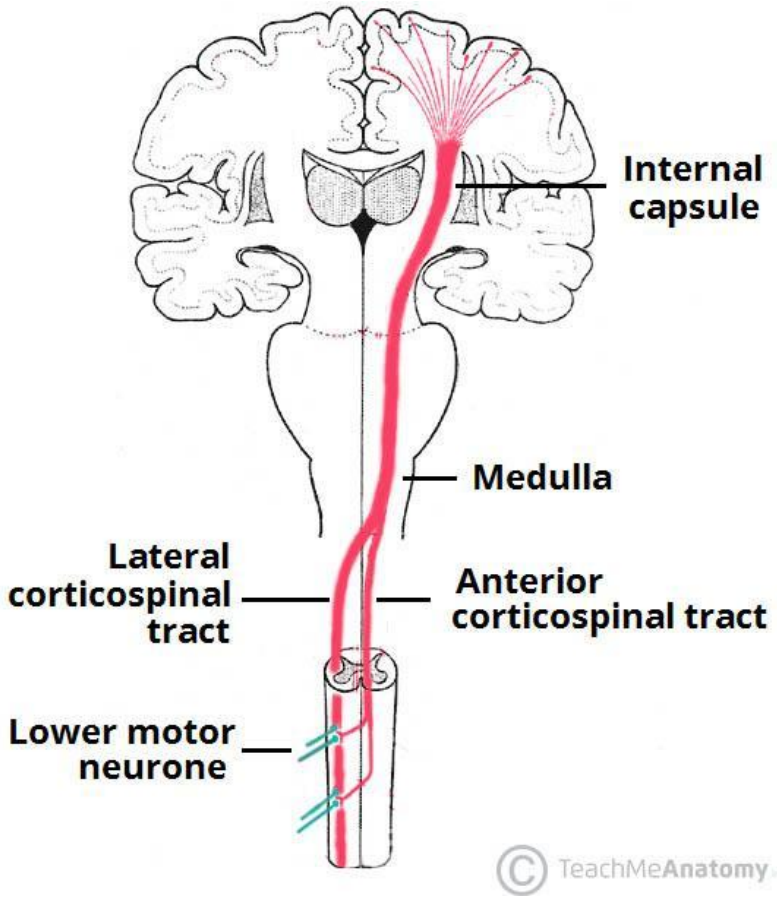
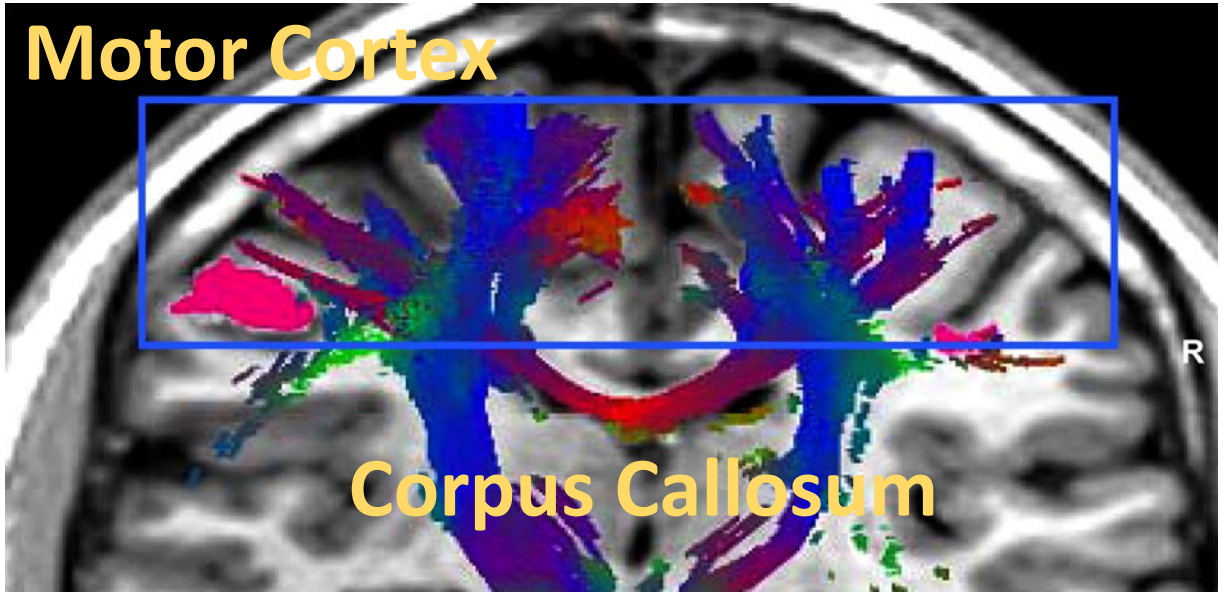
Motivation: Is computation in motor cortex lateralized?





- Connectivity important for bilateral coordination
- **Both ipsilateral and contralateral motor cortex are activated for movement**
- Unclear to what degree responses in both hemispheres are limb-dependent

- M1 lesions Contralateral muscle deficits
- M1 microstimuluation Contralateral muscle activation

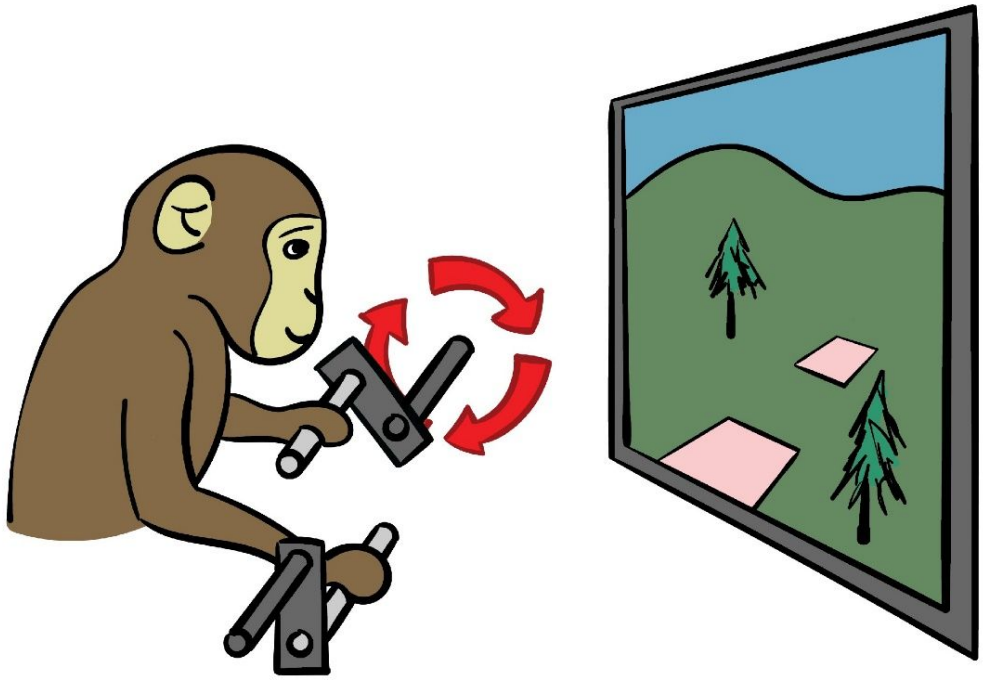
https://teachmeanatomy.info/neuroanatomy/pathways/descending-tracts-motor/
Wahl et. al Journal of Neuroscience 7 November 2007, 27 (45) 12132-12138

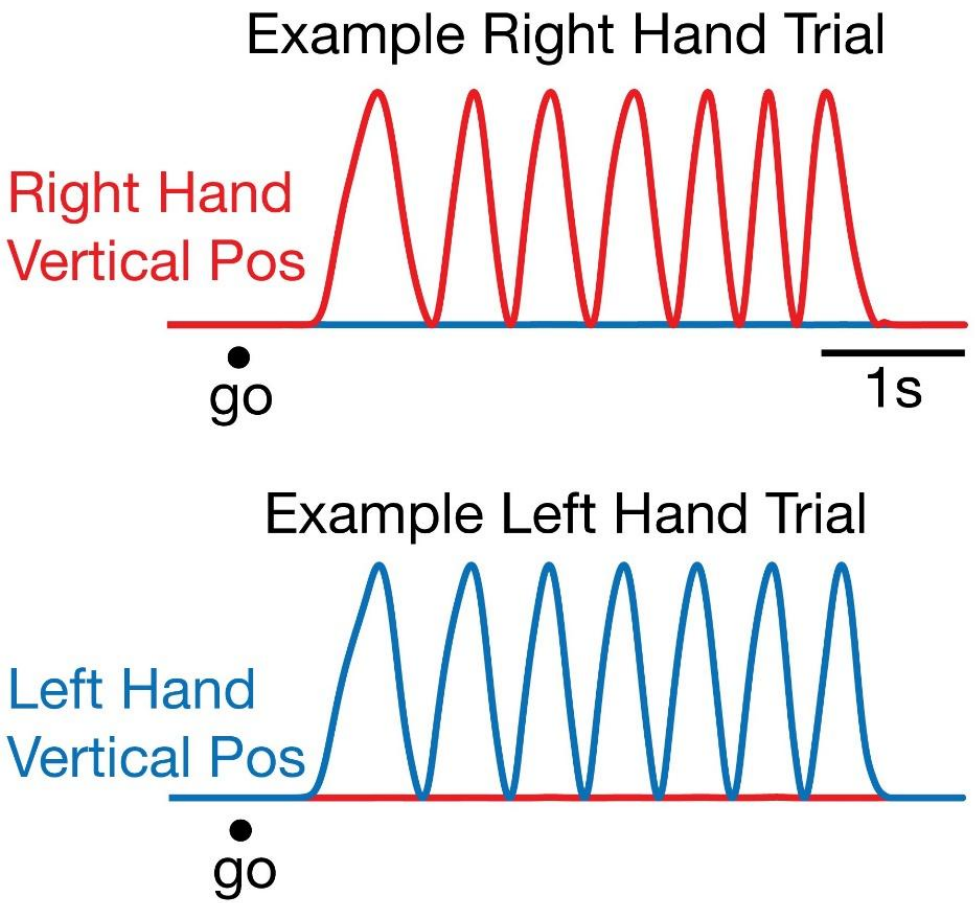
Main Questions

1. To what extent is there muscle-related activity in ipsilateral cortex?

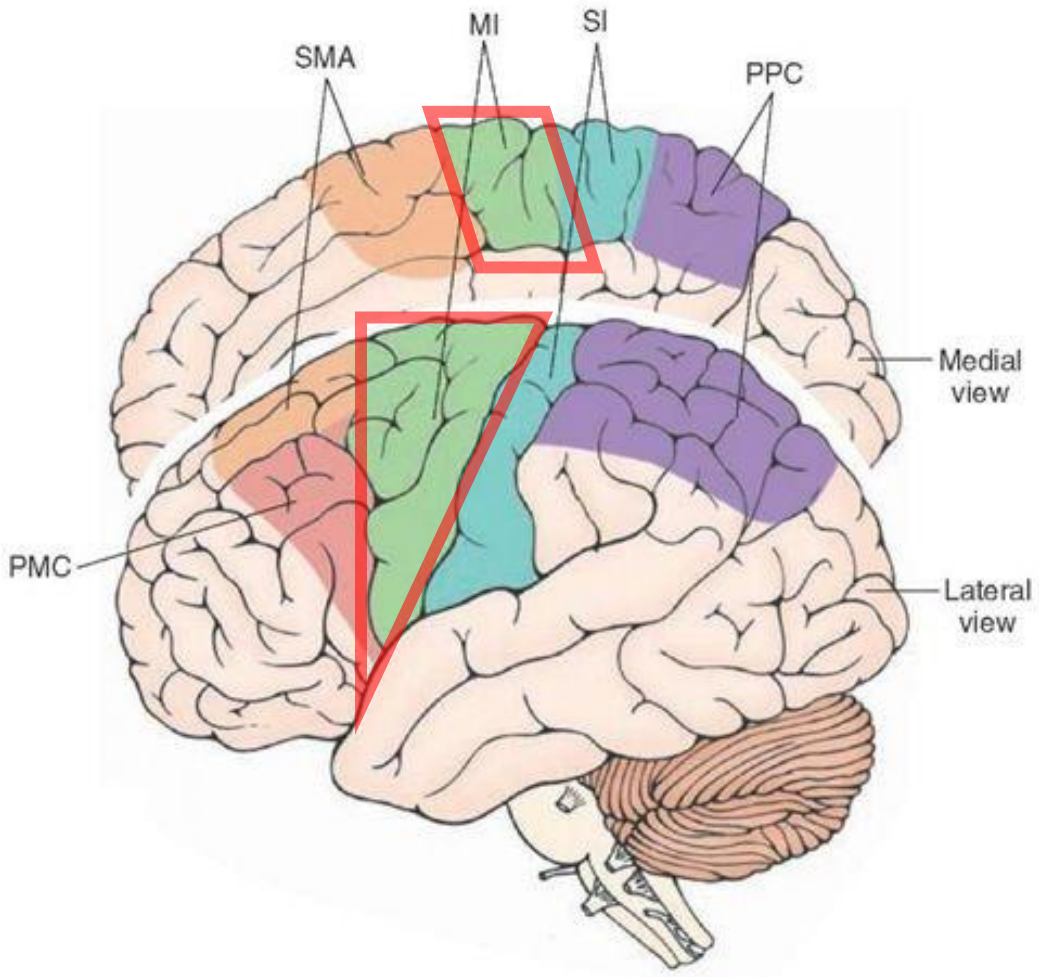
2. How does the information content/structure of that activity compare with the contralateral cortex?

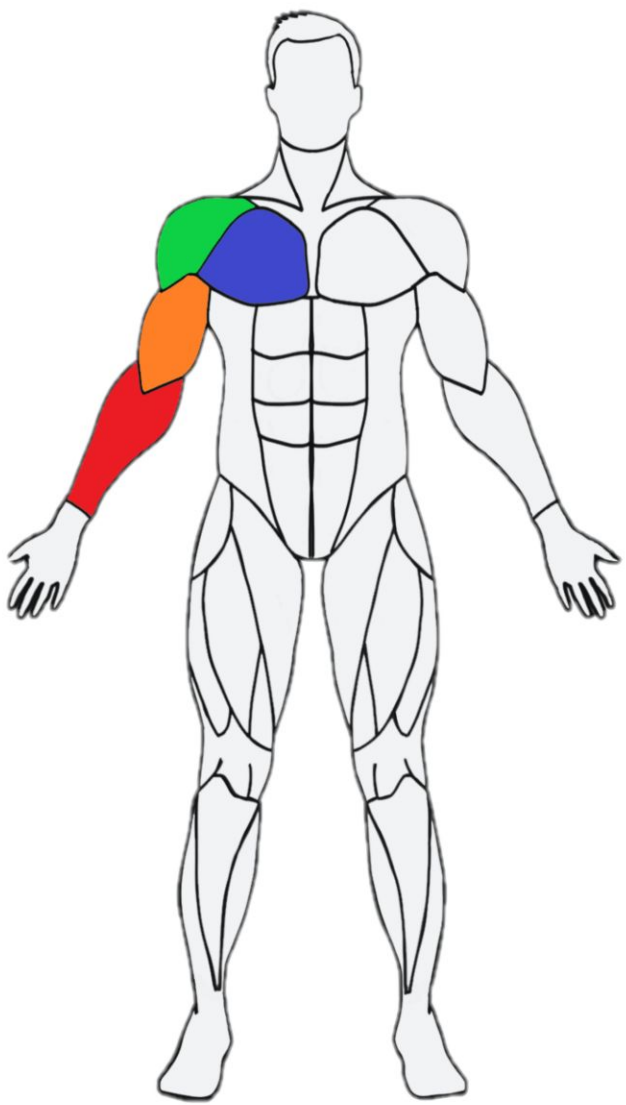
Experimental Paradigm – Cycling Task

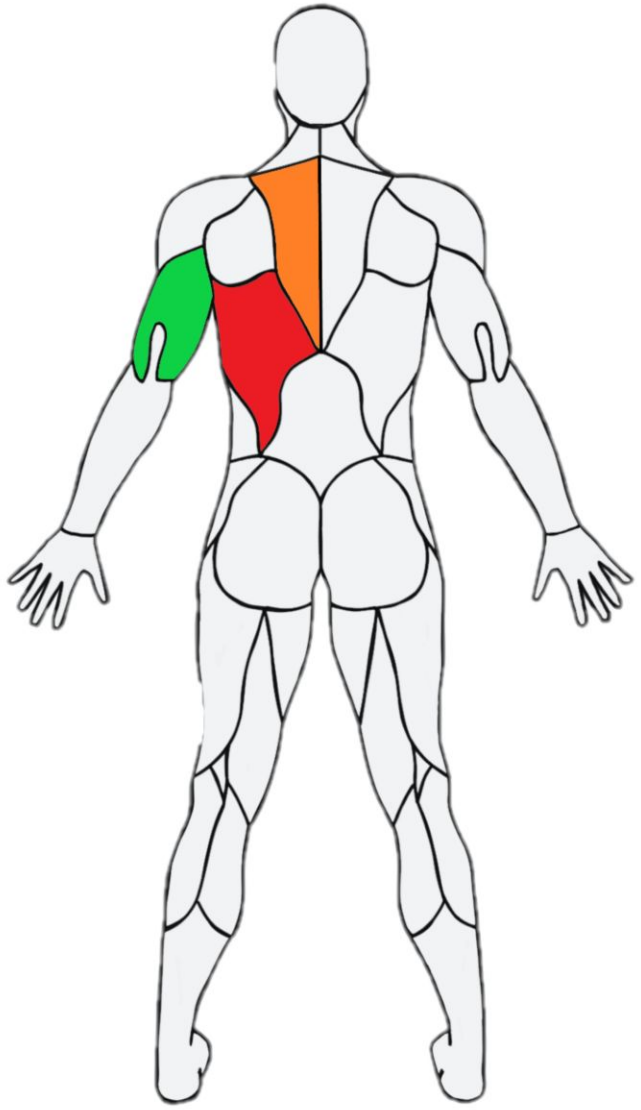




Bilateral M1 and Muscle EMG recordings



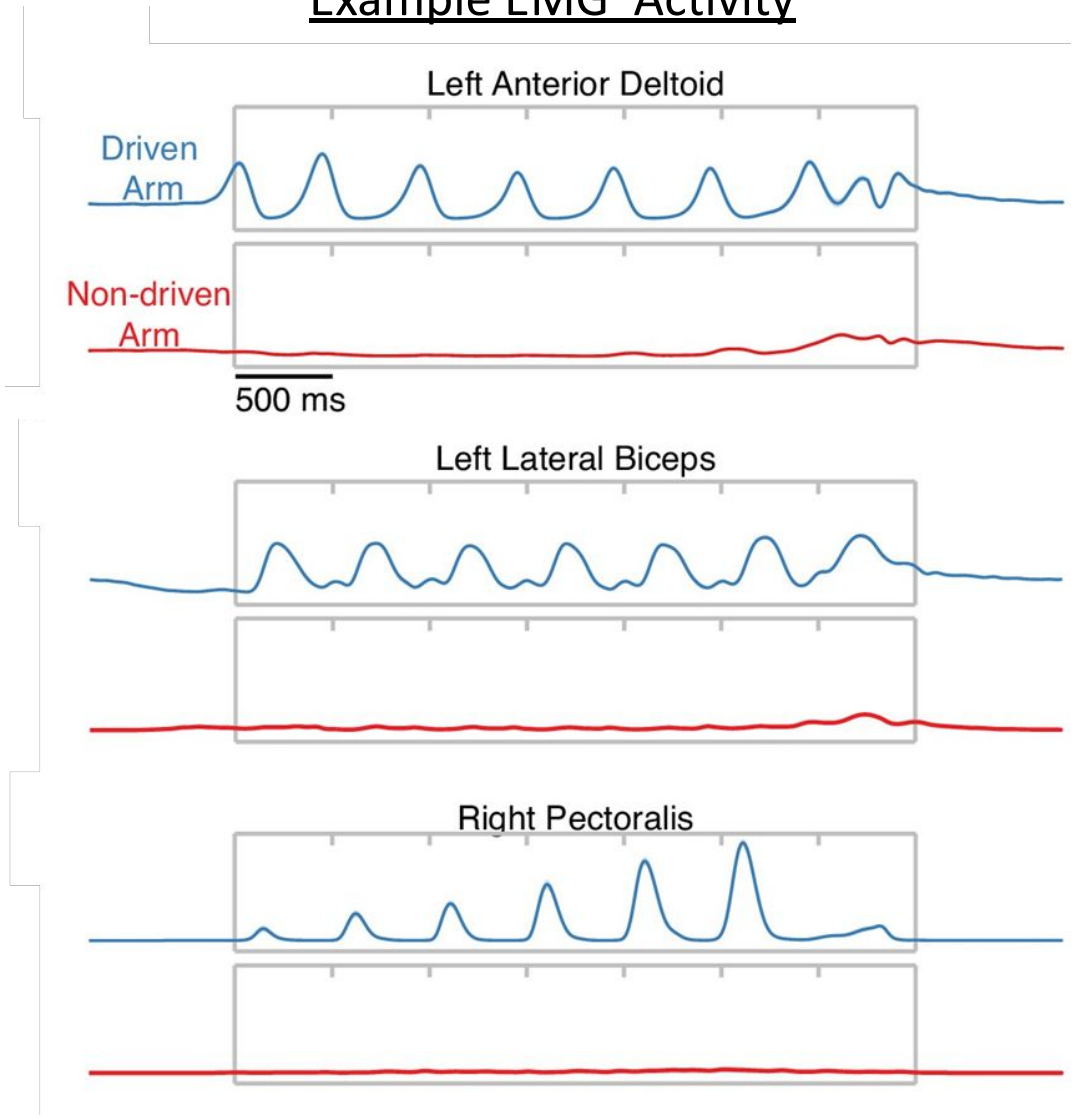




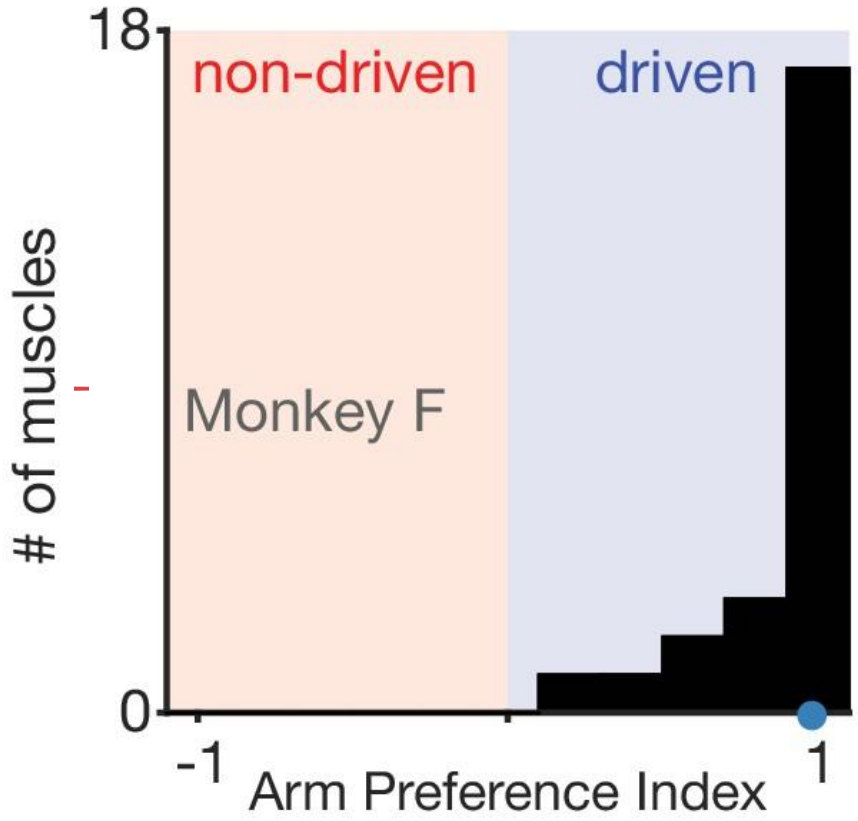
2 monkeys
~500 single units per monkey
24 muscles per monkey

Muscle Activity – Highly Lateralized

Example EMG Activity

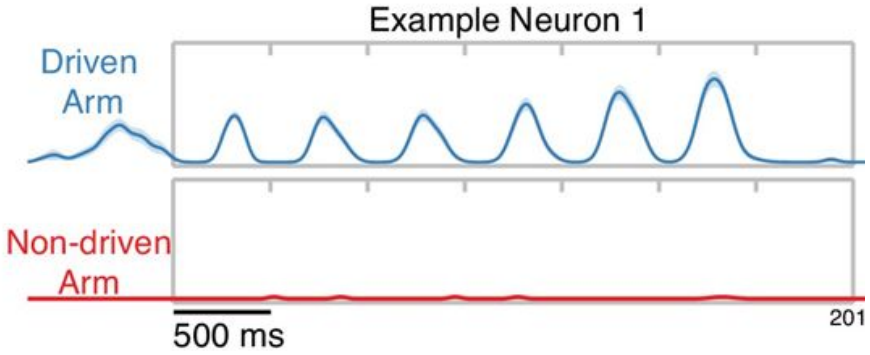


Arm Preference Distrubution



Neural Activity – Limb-dependent with varying preference

Example Neural Activity



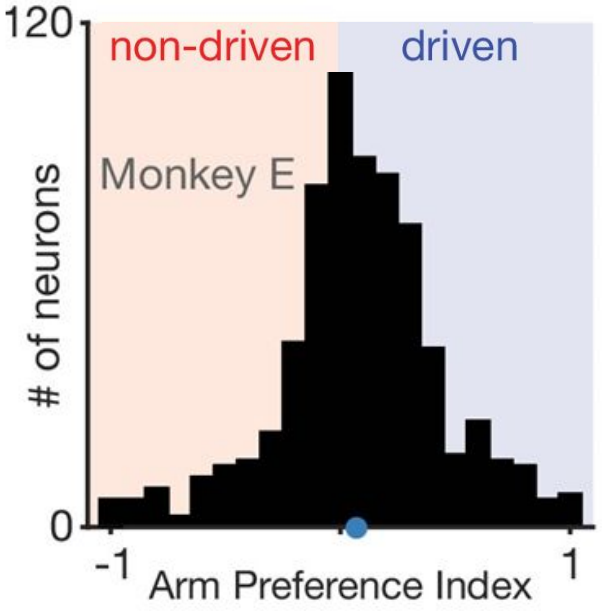
Arm Preference Index

~1

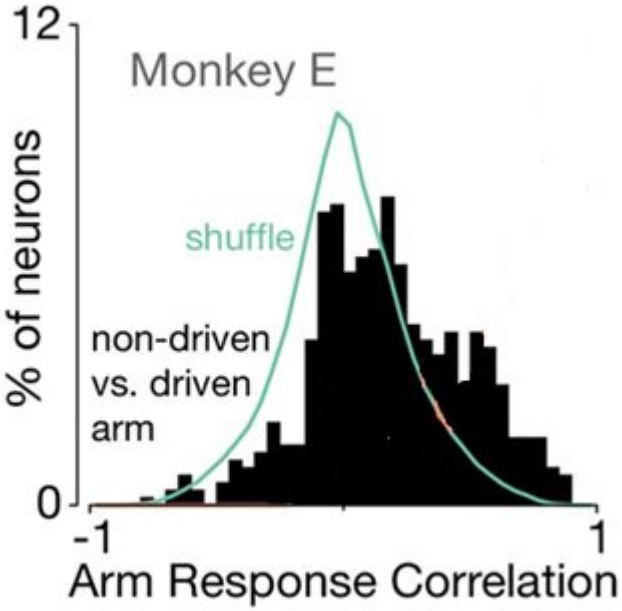
~0

~ -1

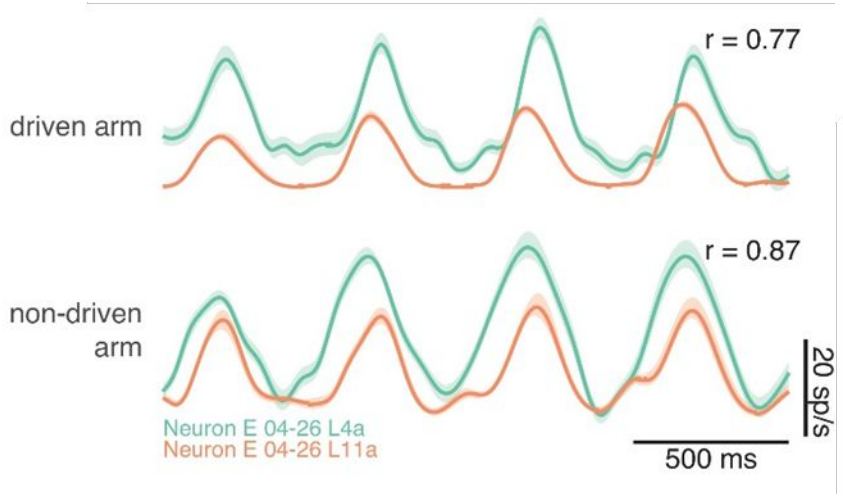
Arm Preference Distrubution

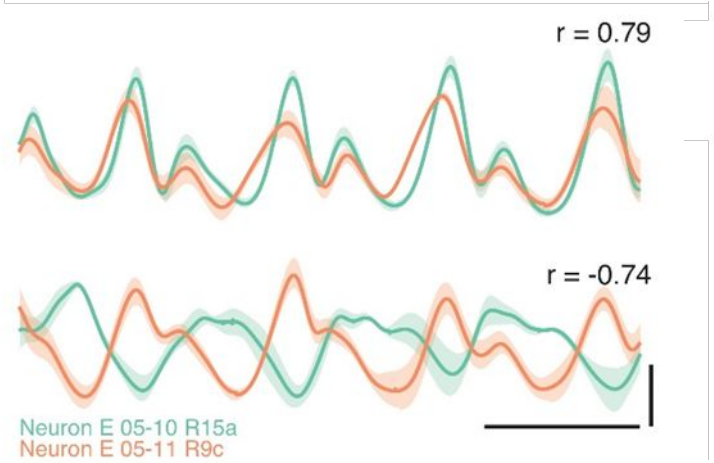


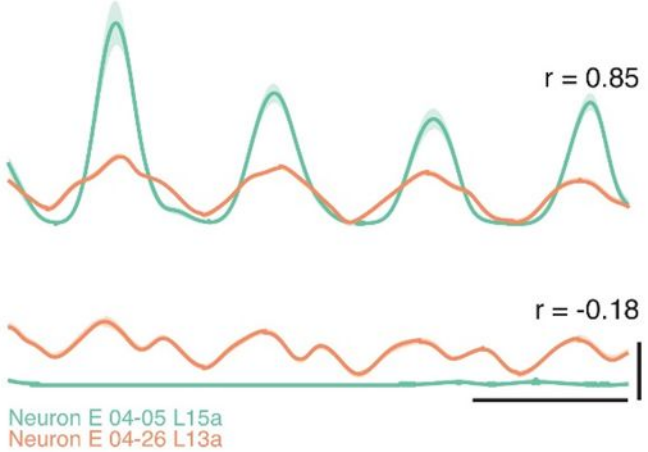
Within Neuron Correlations



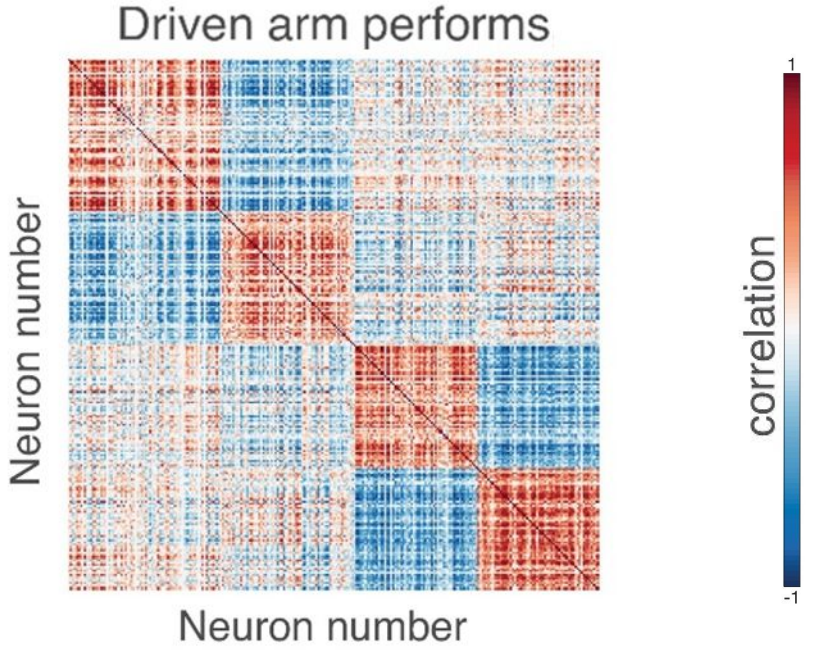
Neural Correlations are Limb-Dependent

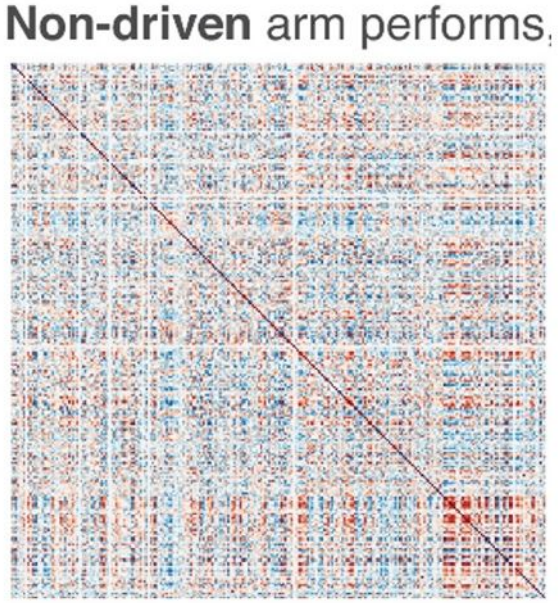




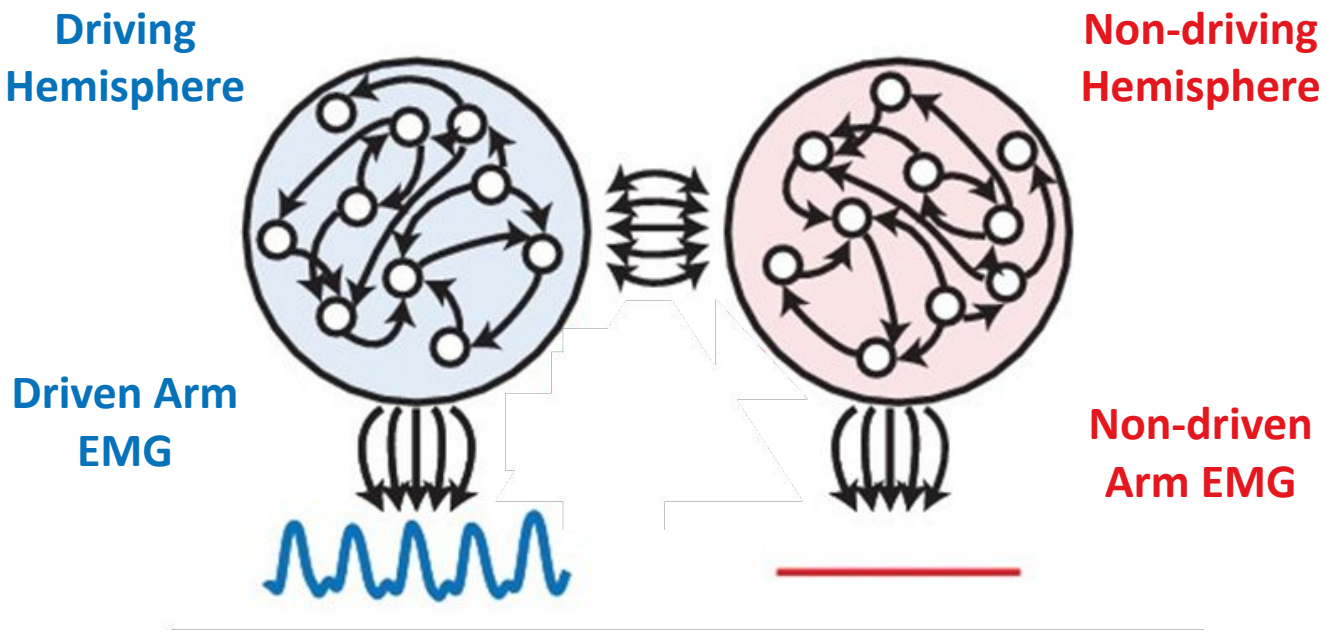


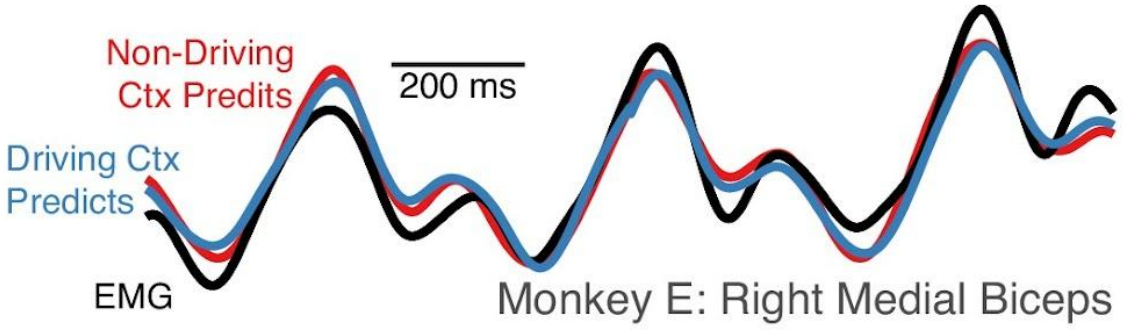
From single hemisphere

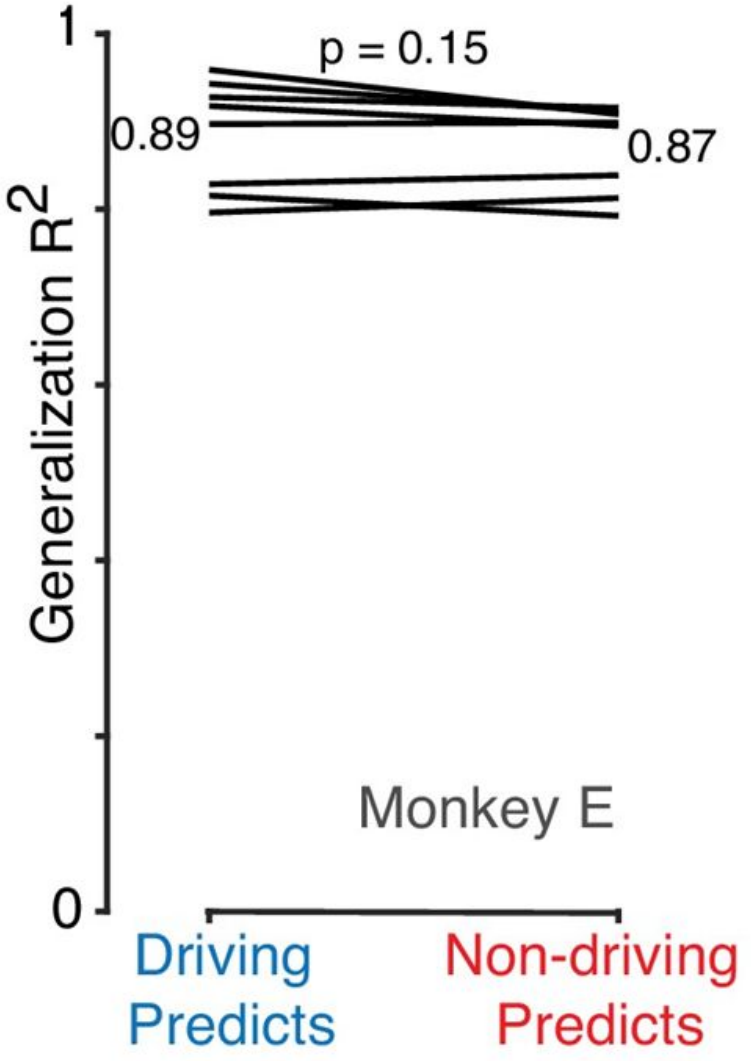




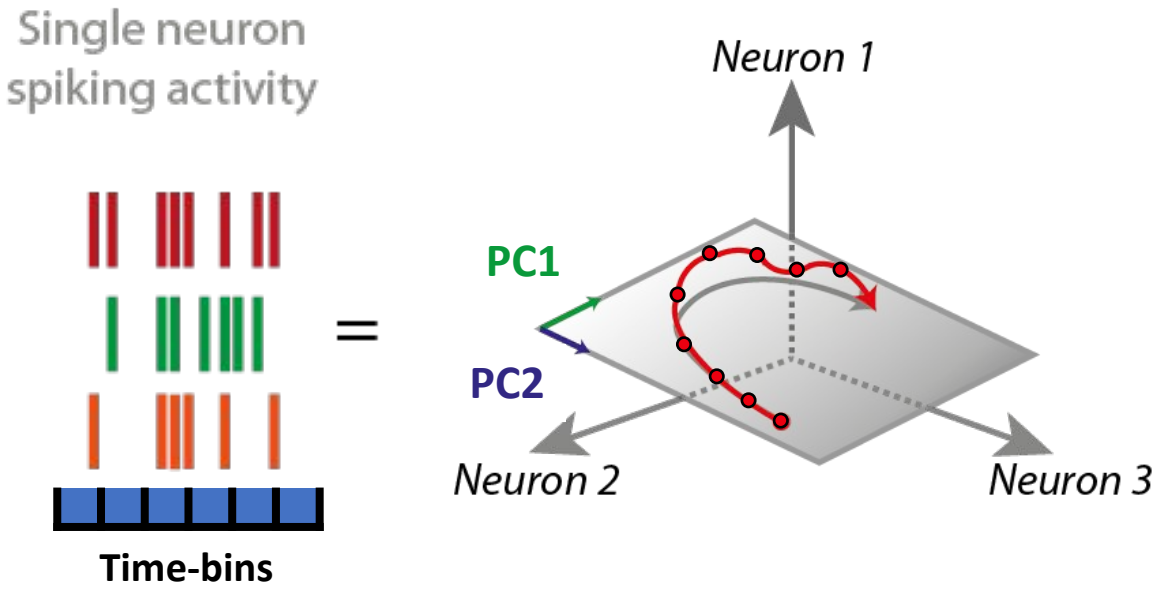
Both hemispheres contain muscle-related activity

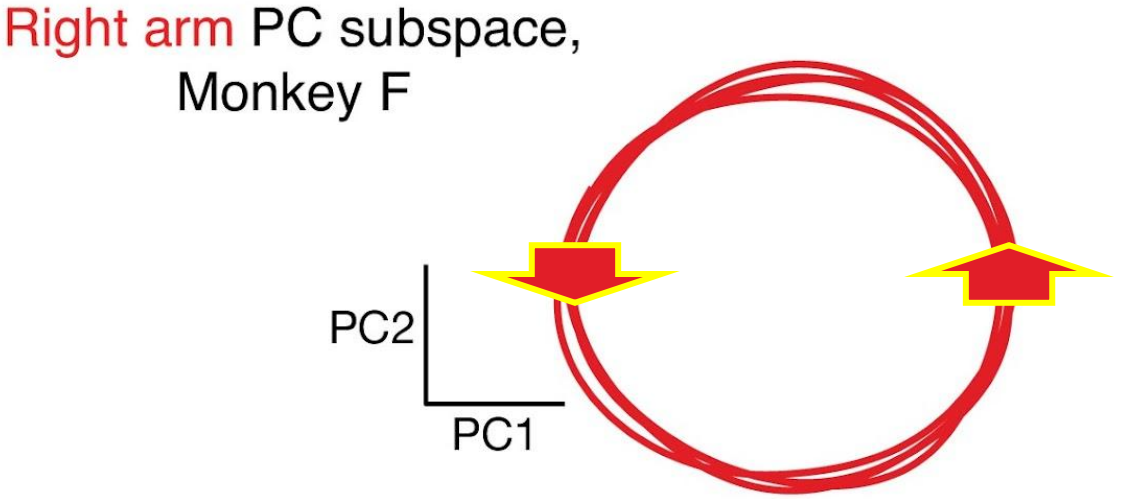






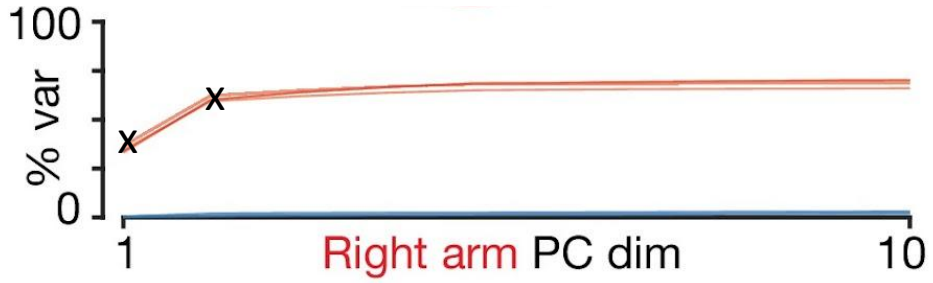
Refresher on population trajectory and PCA



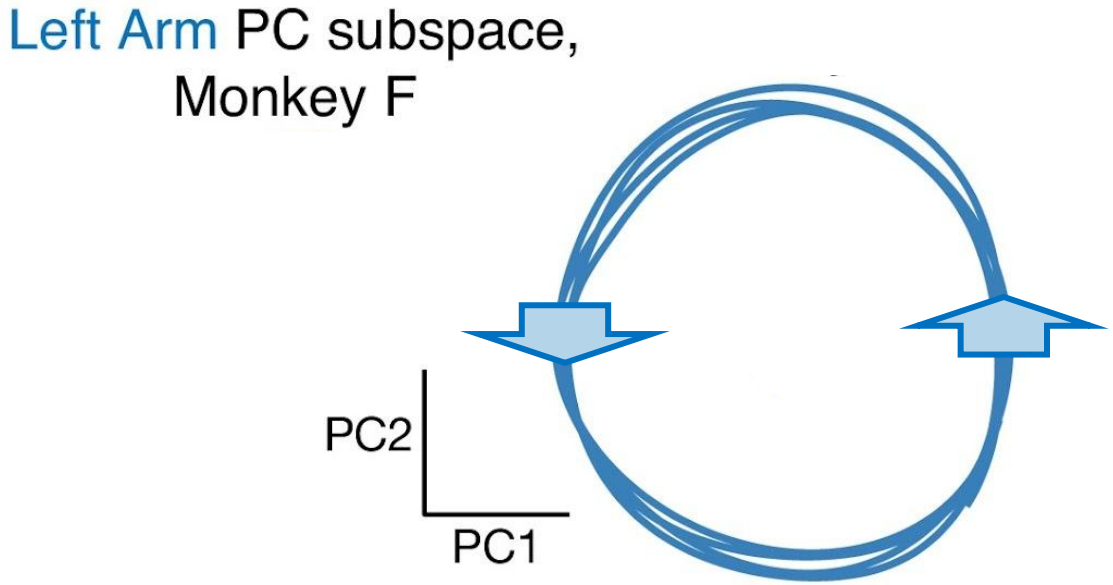


Variance explained:

PCs of **pooled activity from both hemispheres**

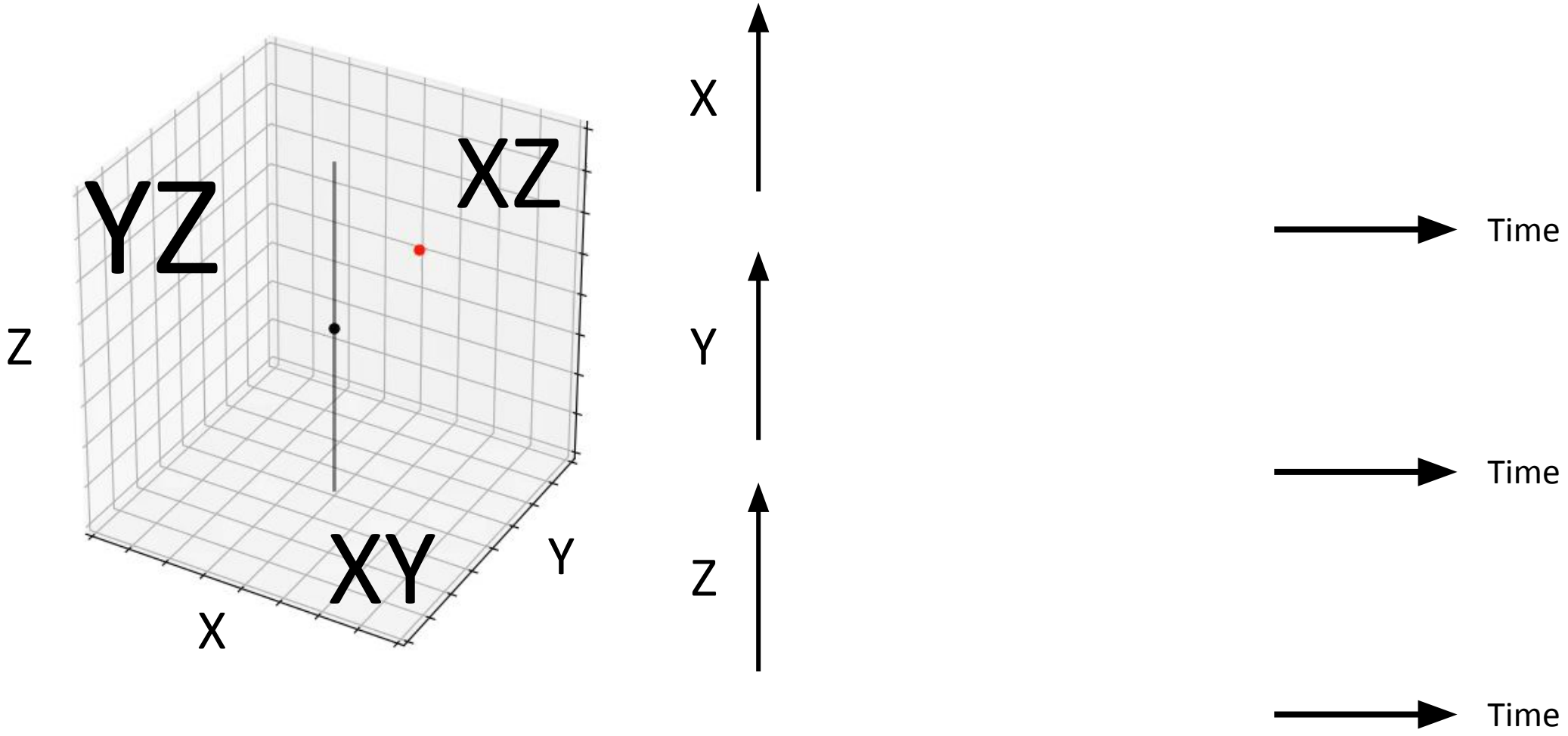


2 PCs explain ~30% of variance each

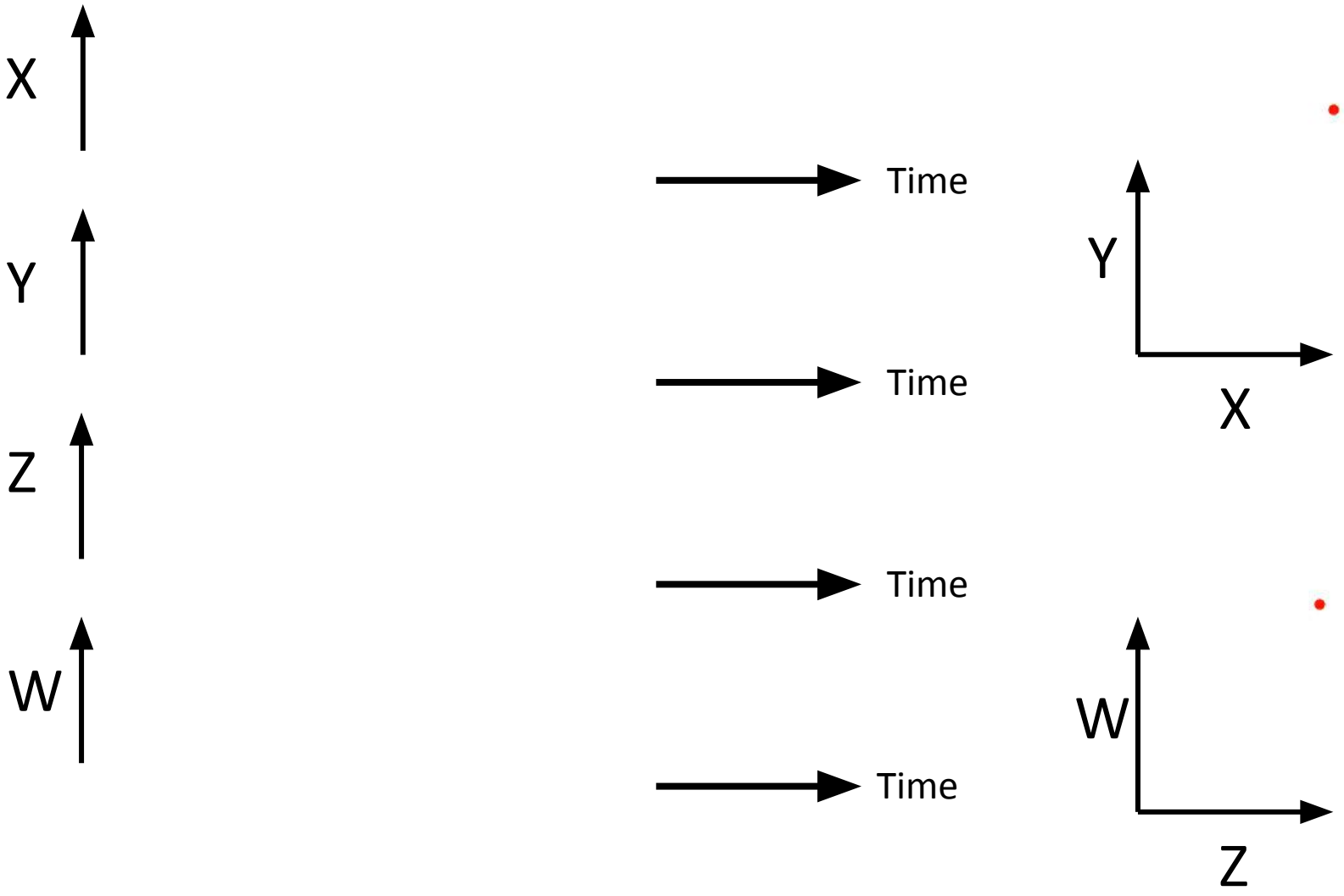


"Neural Manifolds for the Control of Movement", J. A. Gallego, M. G. Perich, L. E. Miller, S. A.Solla

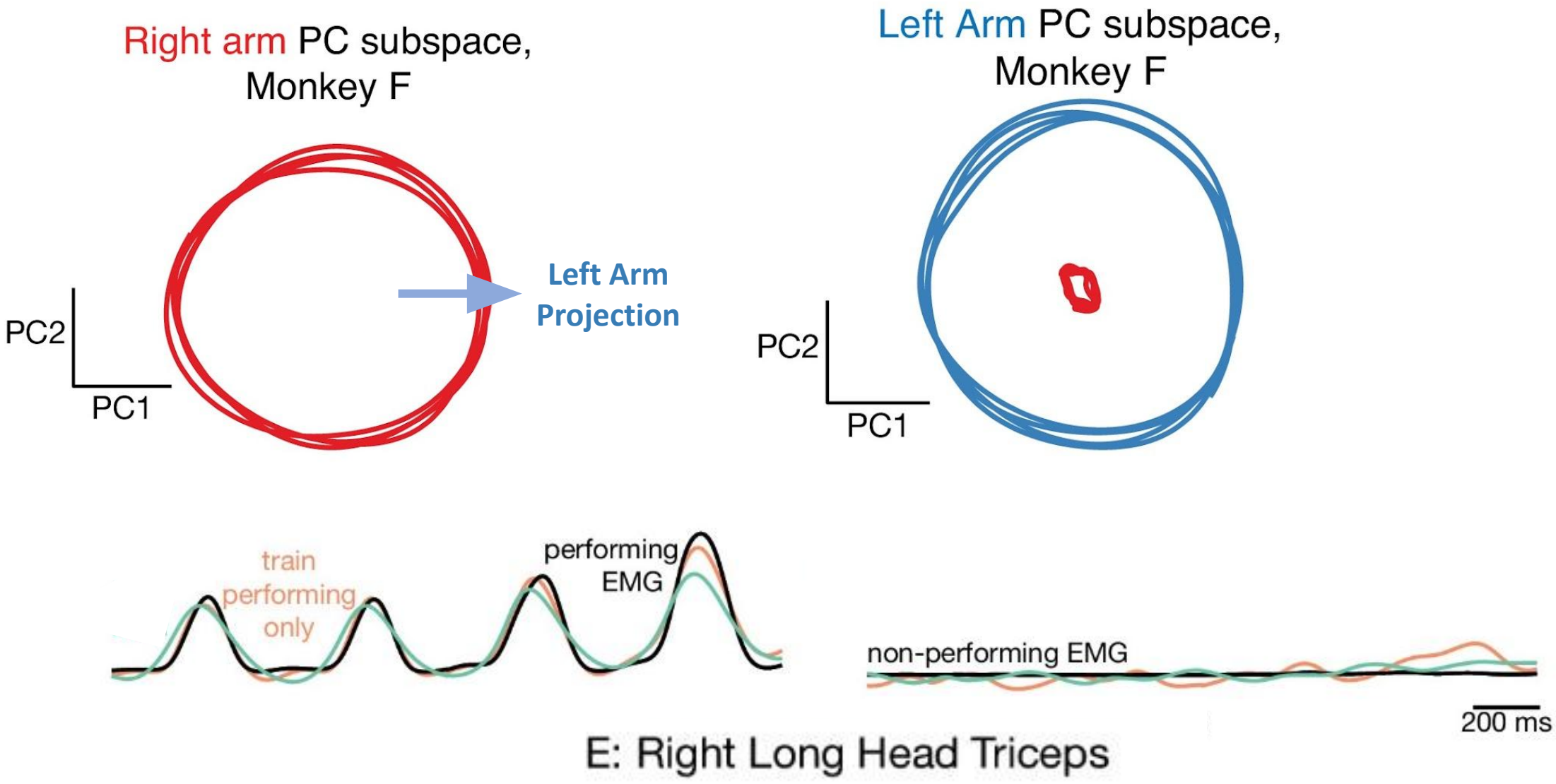
Orthogonal trajectories: 3D



Orthogonal trajectories: 4D



Trajectories of population activity for arms are orthogonal



Summary:

1. Signals related to muscle movement are distributed across neurons in both hemispheres
2. Both hemispheres may behave as a single computational unit to generate motor output
3. Lateralization of motor output can be determined from the population trajectory

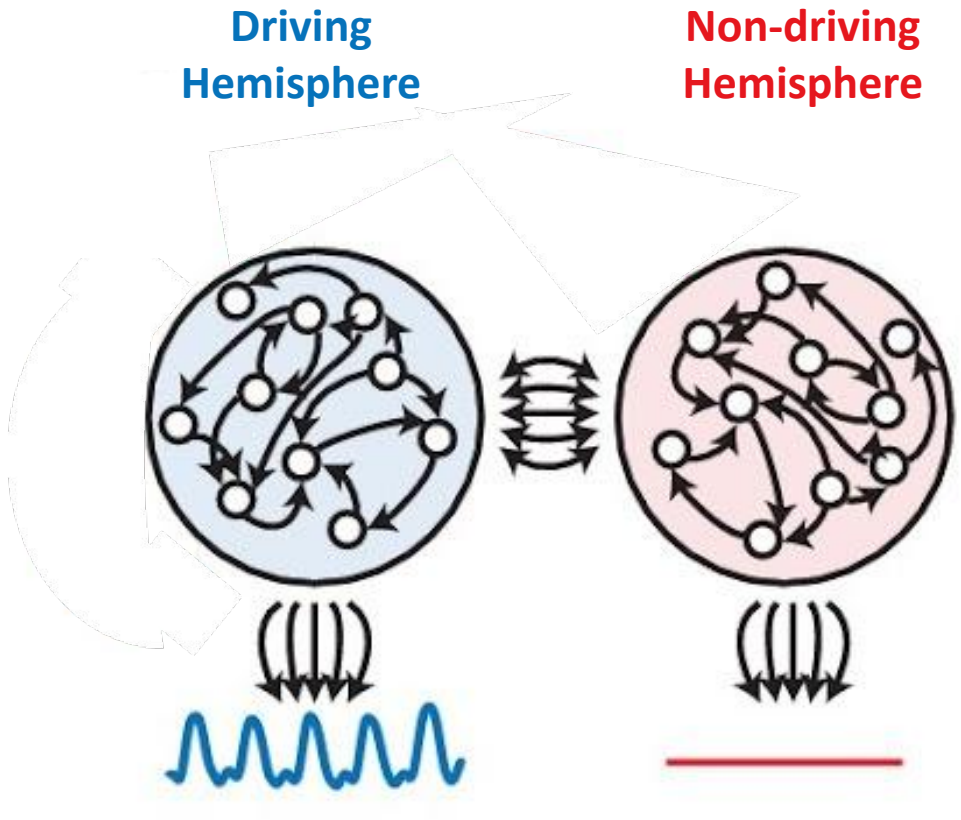
Questions?

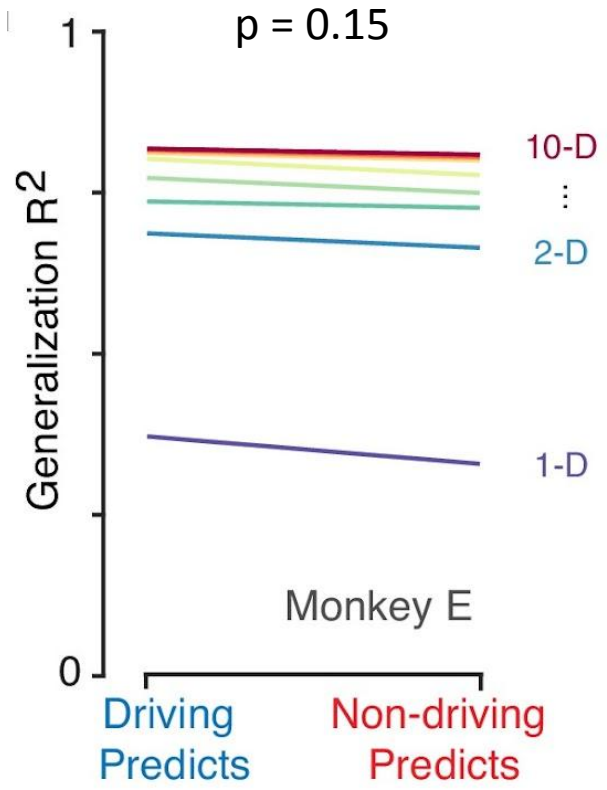
Questions?

- What happens when both arms used:
  - Projection to subspace for each arm equally?
- Literature shows suppression of ipsilateral motor cortex:
  - How strongly does that affect the orthogonality of the trajectories?
- What's the point of signal being in both cortices?
  - Efference copy for coordination
  - Efference copy for transfer of learning?
  - How much information is transferred via corpus callosum connections?

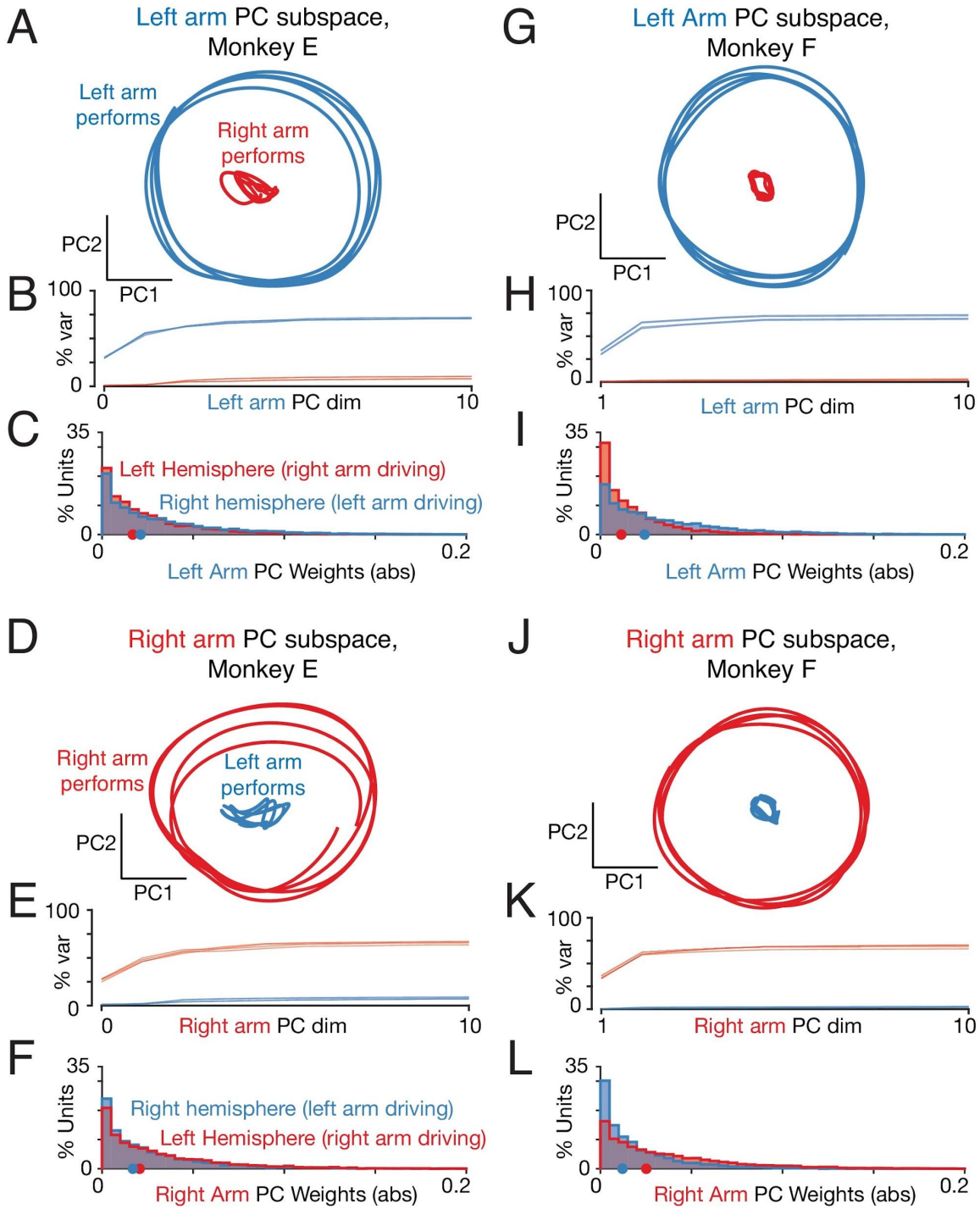
Supplement

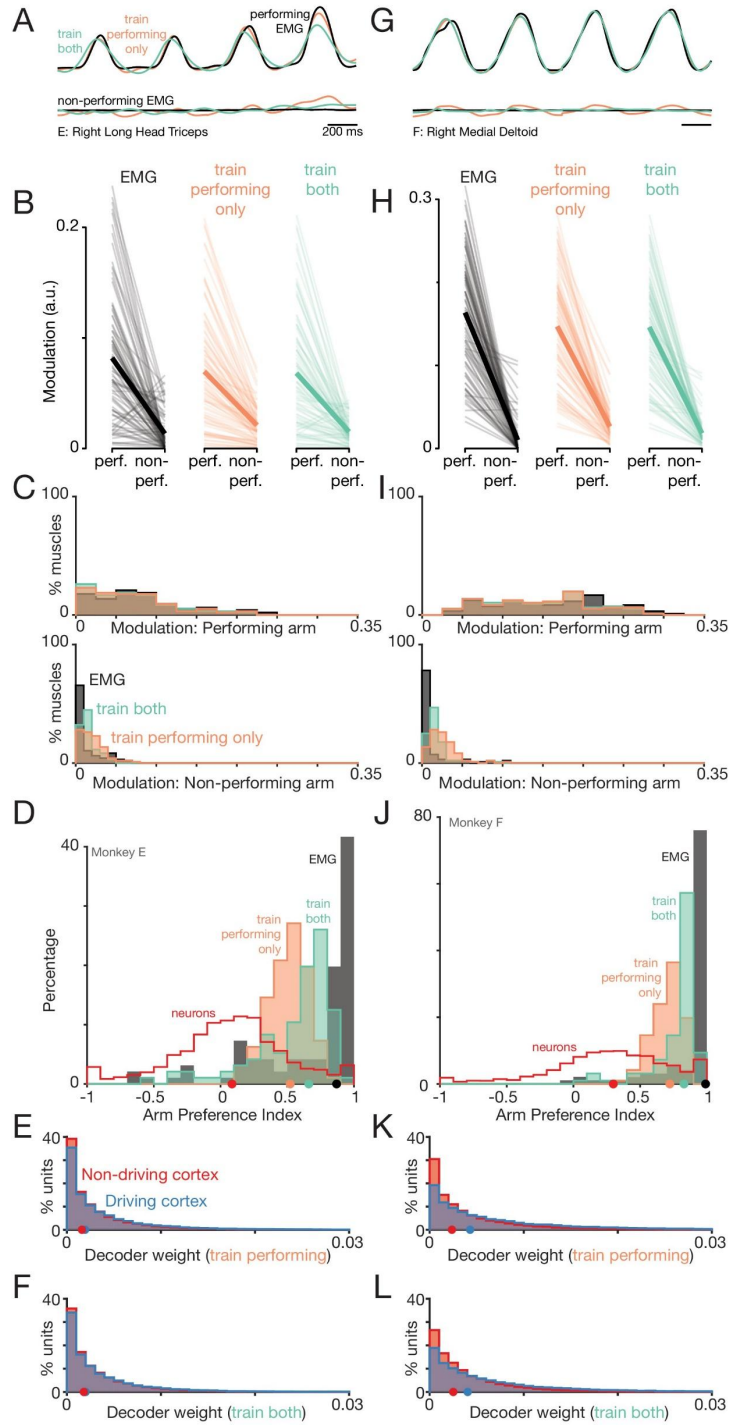
Non-driving hemisphere can predict driving hemisphere



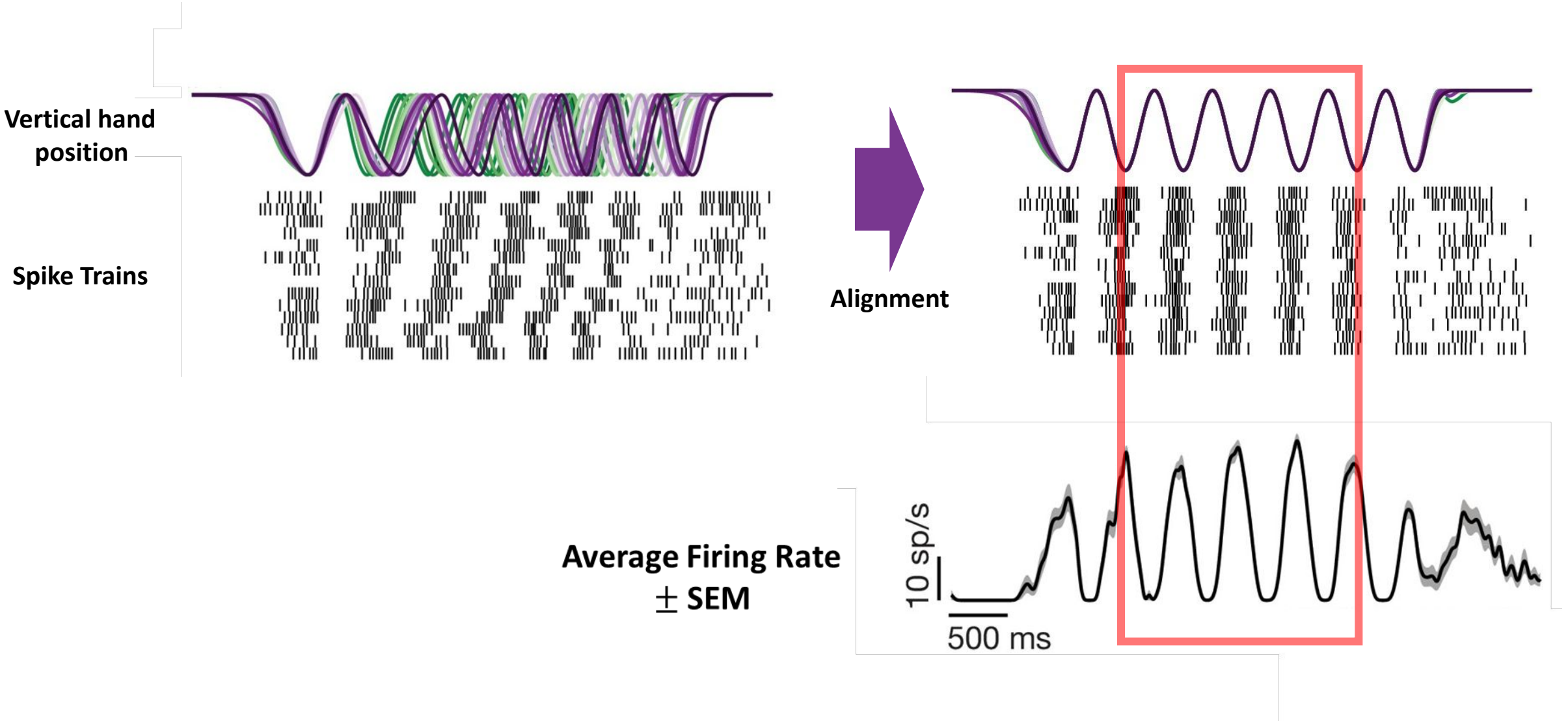


Previous two results show that major signals are shared between both hemispheres

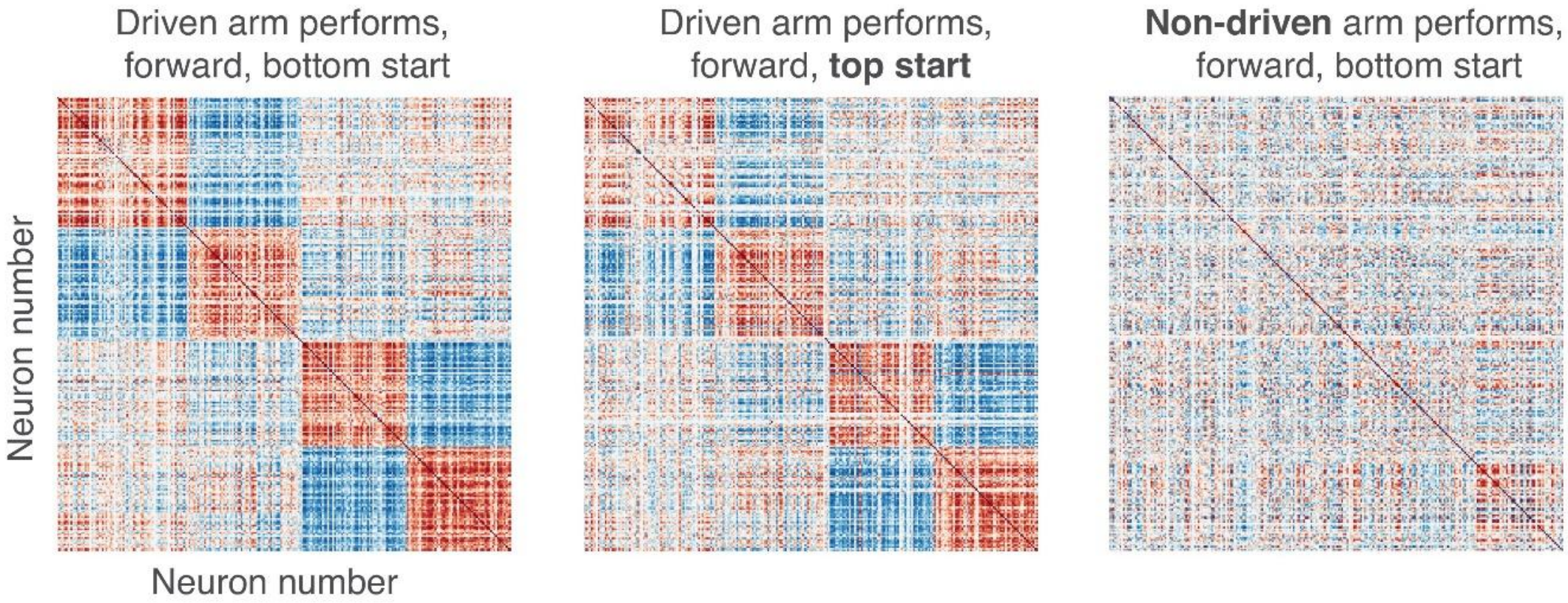

A
Left arm PC subspace,
Monkey E
Left arm
performs
Right arm
performs
PC2
PC1
B
100
% var
0
0
Left arm PC dim
10
C
35
% Units
0
Left Hemisphere (right arm driving)
Right hemisphere (left arm driving)
0
0.2
Left Arm PC Weights (abs)
G
Left Arm PC subspace,
Monkey F
PC2
PC1
H
100
% var
0
1
Left arm PC dim
10
I
35
% Units
0
0
0.2
Left Arm PC Weights (abs)
D
Right arm PC subspace,
Monkey E
Right arm
performs
Left arm
performs
PC2
PC1
E
100
% var
0
0
Right arm PC dim
10
F
35
% Units
0
Right hemisphere (left arm driving)
Left Hemisphere (right arm driving)
0
0.2
Right Arm PC Weights (abs)
J
Right arm PC subspace,
Monkey F
PC2
PC1
K
100
% var
0
1
Right arm PC dim
10
L
35
% Units
0
0
0.2
Right Arm PC Weights (abs)


A
train both
train performing only
performing EMG
non-performing EMG
E: Right Long Head Triceps
200 ms
G
F: Right Medial Deltoid
B
EMG
train performing only
train both
Modulation (a.u.)
0.2
0
perf. non-perf.
H
0.3
C
% muscles
100
Modulation: Performing arm
0.35
EMG
train both
train performing only
Modulation: Non-performing arm
I
D
Monkey E
Percentage
neurons
-1
-0.5
0.5
1
Arm Preference Index
J
Monkey F
80
E
Non-driving cortex
Driving cortex
% units
Decoder weight (train performing)
0.03
K
F
Decoder weight (train both)
L

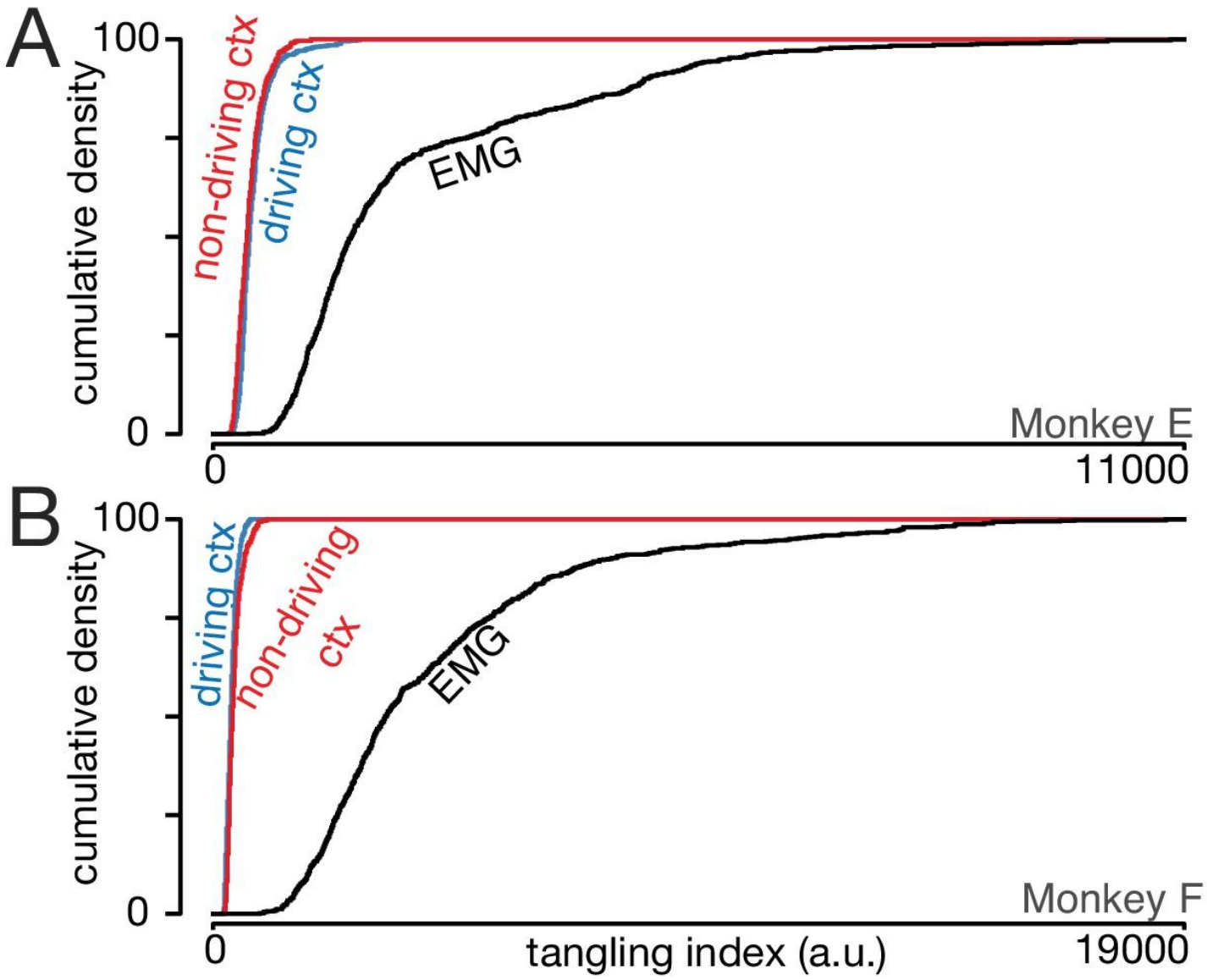
Preprocessing – Alignment of signals



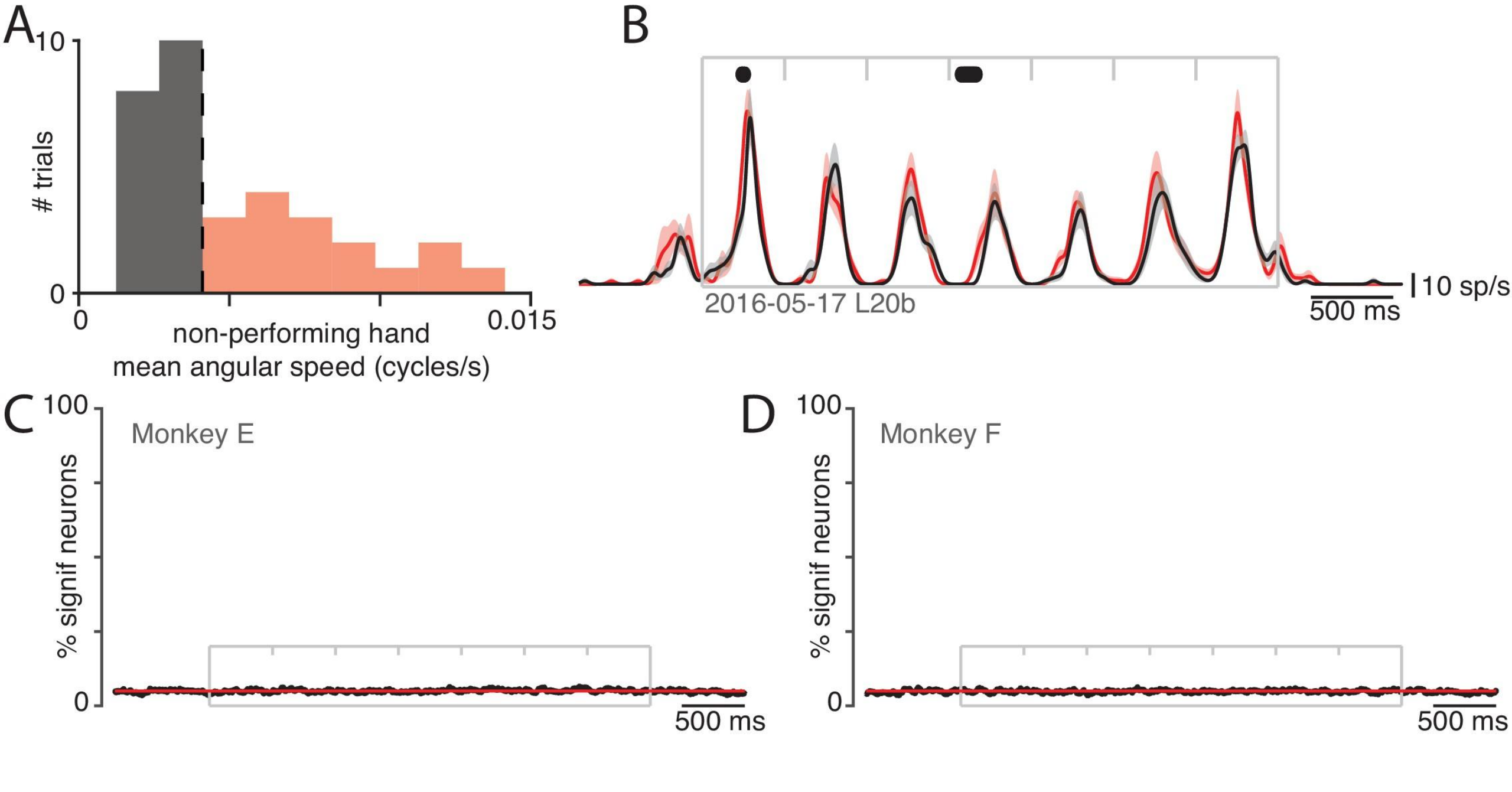
Correlations are robust



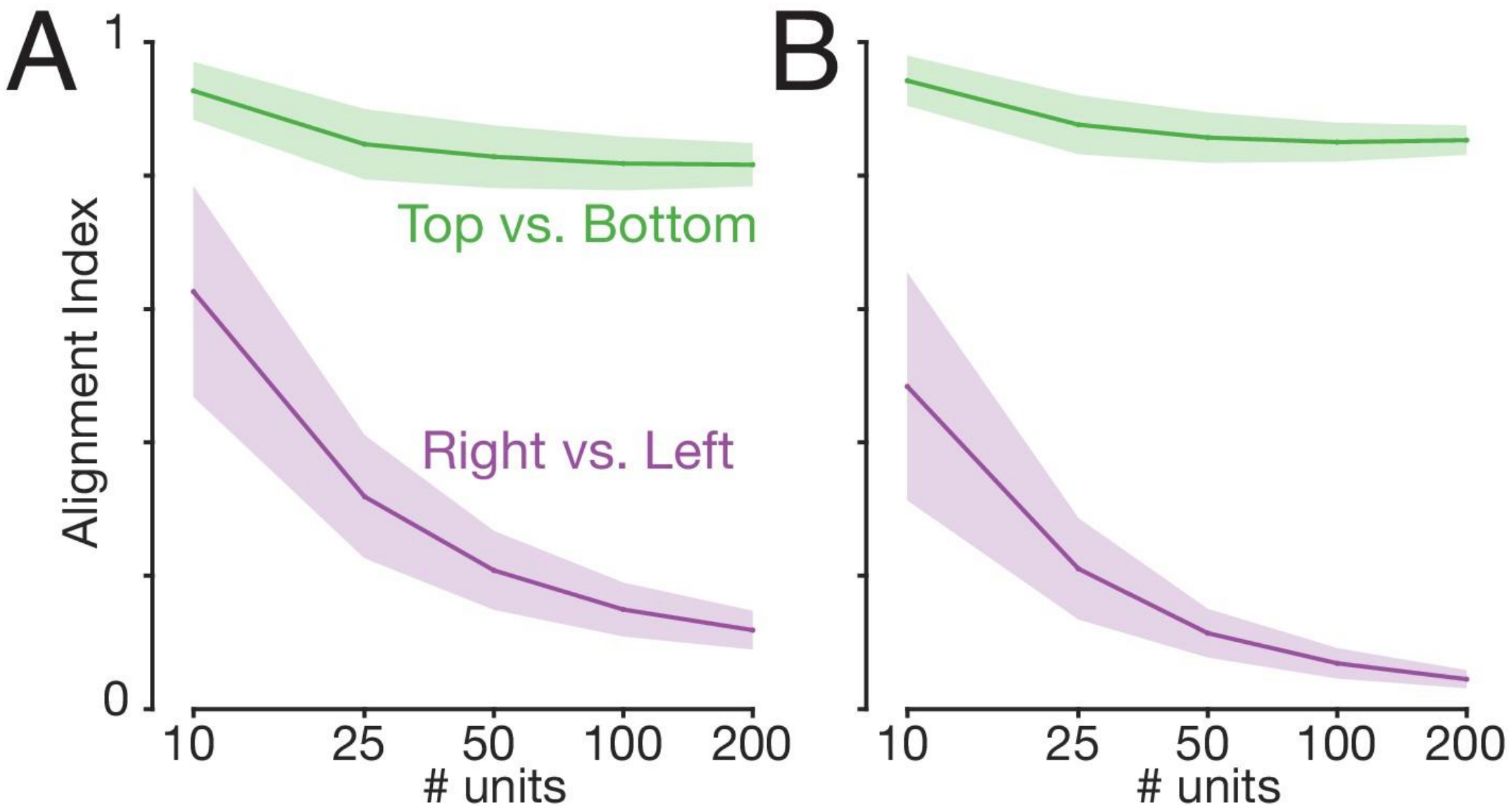
Pictures of tangled vs non-tangled tranjectories



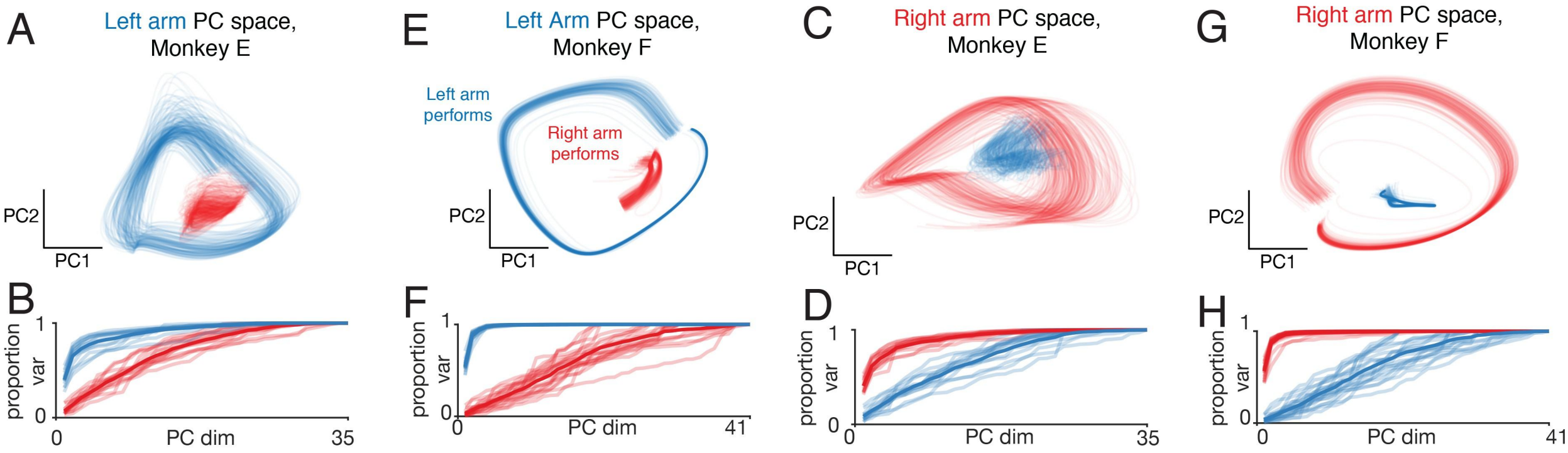
Test for minor activation of non-driven arm



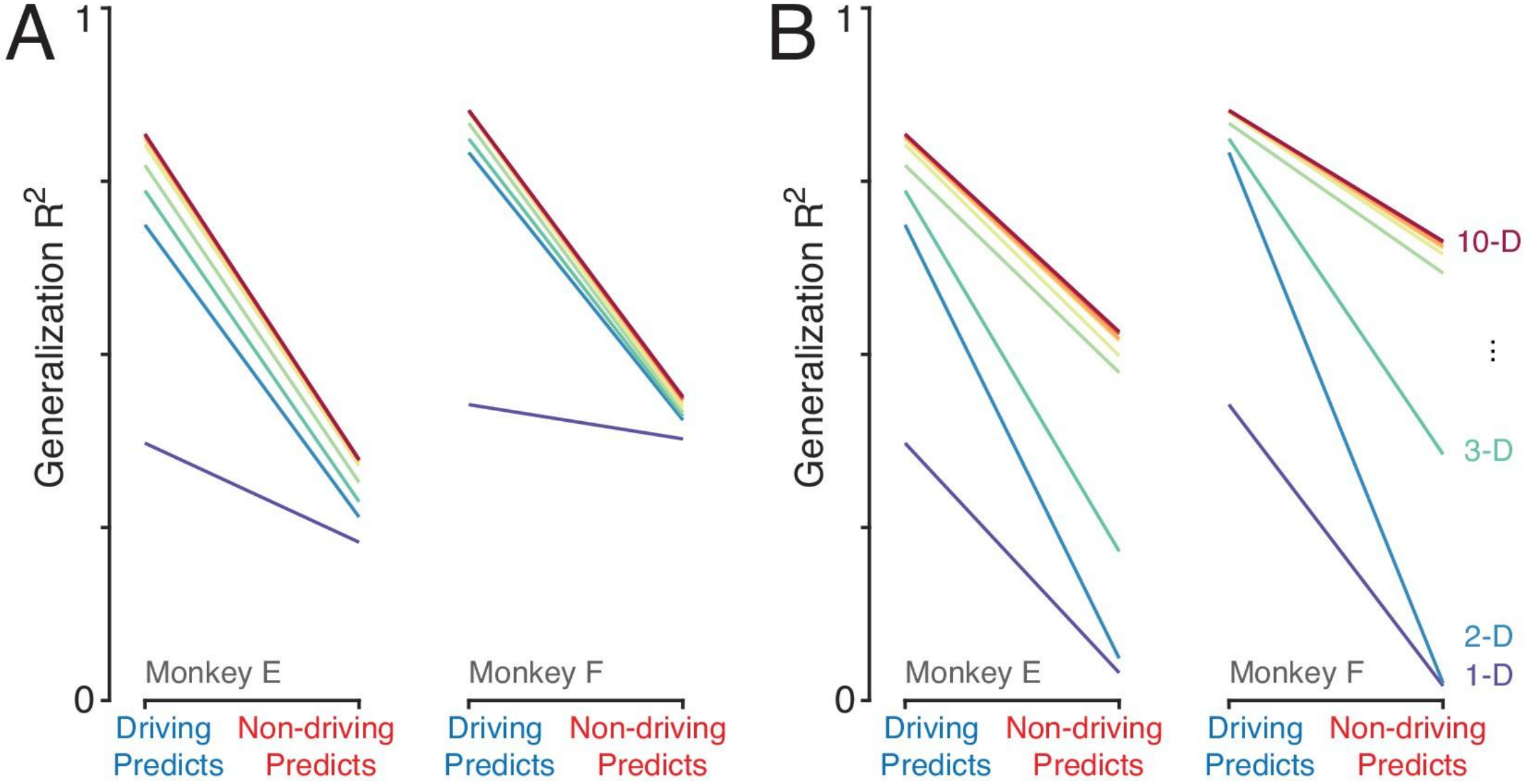
Estimation of subspaces depends on neuron count



Orthogonality repeated with single trial estimates

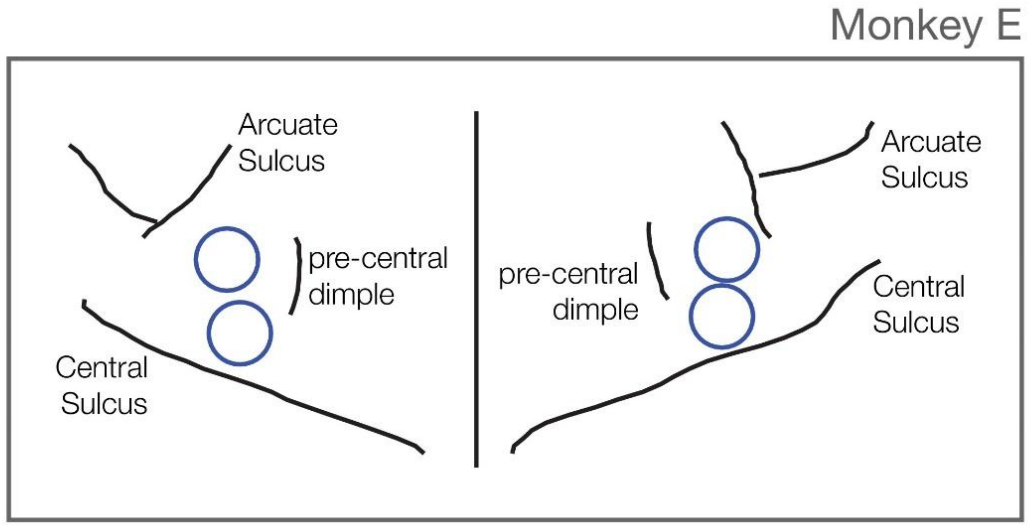


Test for mismatch in signals between hemispheres



Implant sites

F



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