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Article

Condition-Dependent Neural Dimensions Progressively Shift during Reach to Grasp

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Neurobiology Journal Club

Presented by: James Goodman

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Introduction

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Reach-to-grasp behavior: distinct phases

- Reach-to-grasp: show the distinct phases, kinematically

Coupling between arm and hand

- Reach-to-grasp: show kinematic coupling of arm & hand

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Control of reach-to-grasp: distinct pathways

- Reach-to-grasp: show the segregated reach- and grasp-pathways
- Include the putative somatotopy in M1

Mixed information along these pathways

- Reach-to-grasp: show the amount of overlap (at the single-neuronal level) at multiple stages of the movement planning-to-execution hierarchy:
- Lehmann et al. 2013
- Takahashi et al. 2017

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Mixed information in M1

- Reach-to-grasp: show the amount of overlap (at the single-neuronal level) at multiple stages of the movement planning-to-execution hierarchy:
- Schieber's monkey wrench in M1 somatotopy
- Rouse & Schieber 2016

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What, then, separates reach & grasp?

- Could there be a distinction at the population level?
- If so, what might the nature of this distinction be?
  - Object-vs-location dichotomy?
  - Early-vs-late dichotomy?
  - No dichotomy at all?
- What fraction of activity is location-, object-, or even task-modulated?

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Methods

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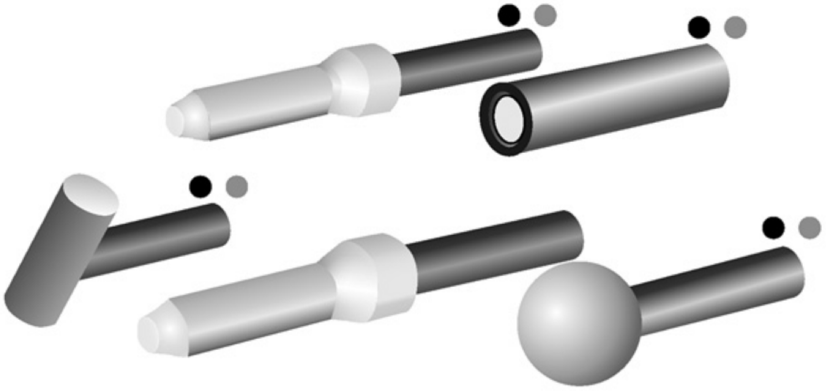
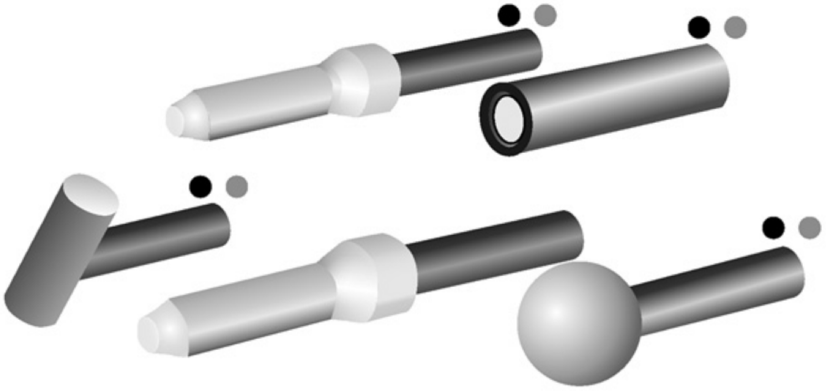
Experiment



Mollazadeh *et al*. 2011 *J Neurosci.*

Experiment



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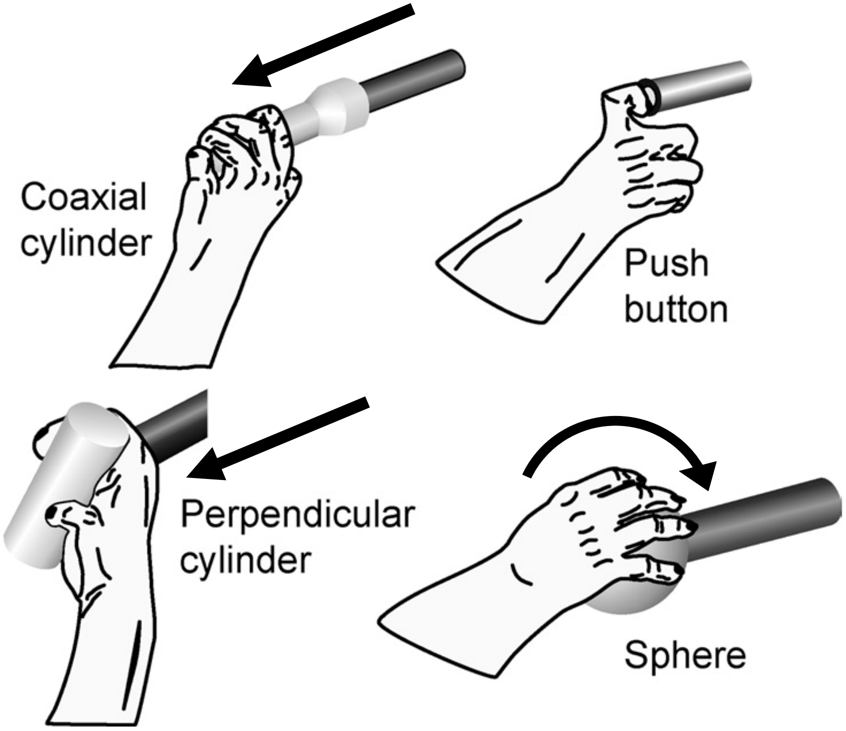
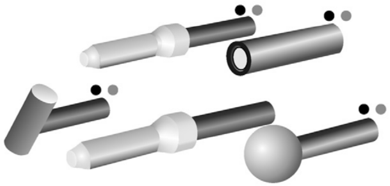


Mollazadeh *et al*. 2011 *J Neurosci.*

Monkey “Bop-It”

Trial Structure



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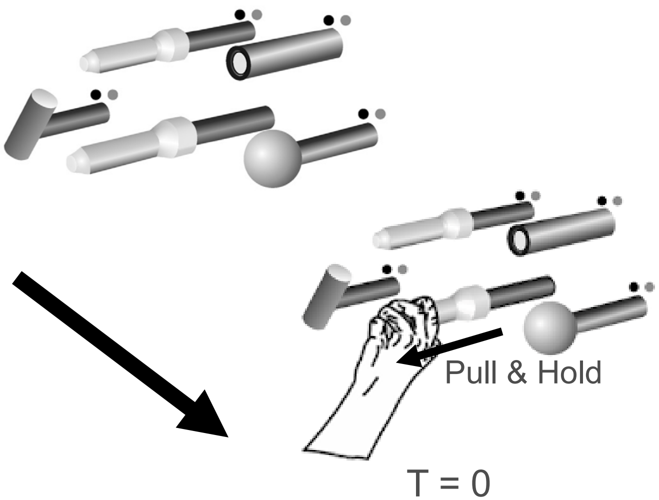

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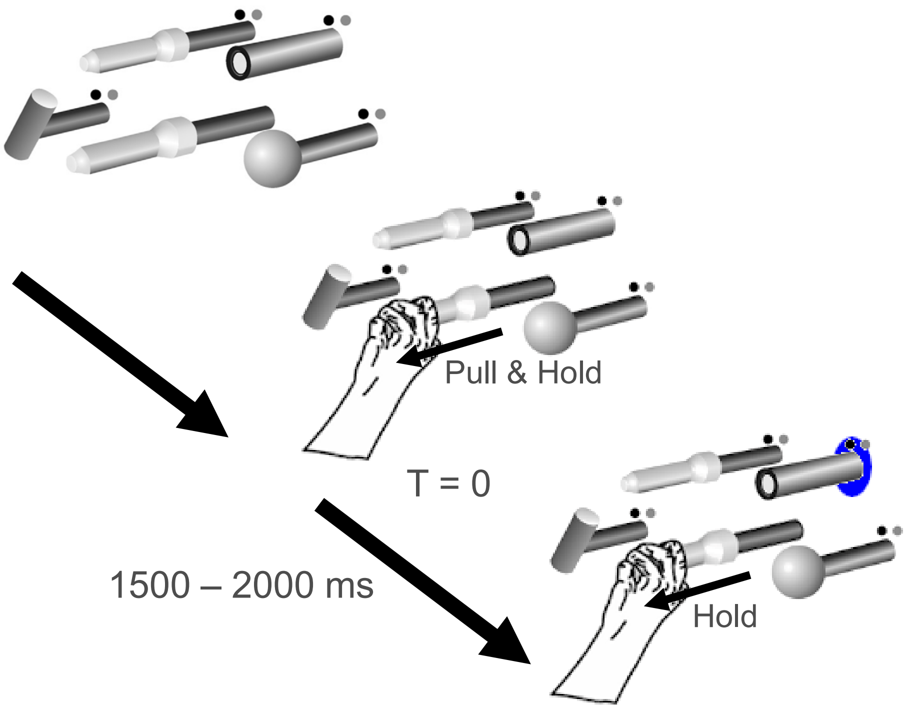

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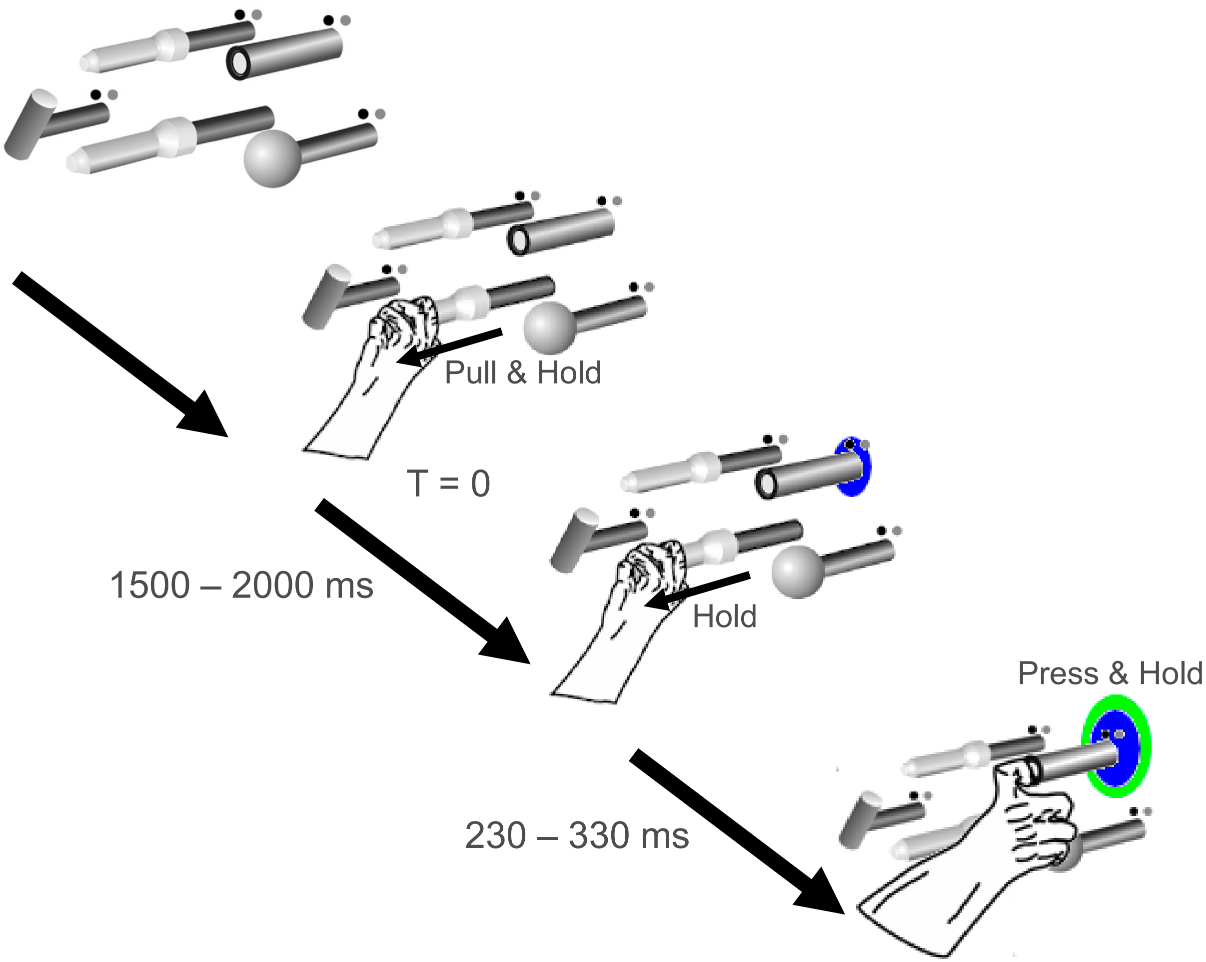

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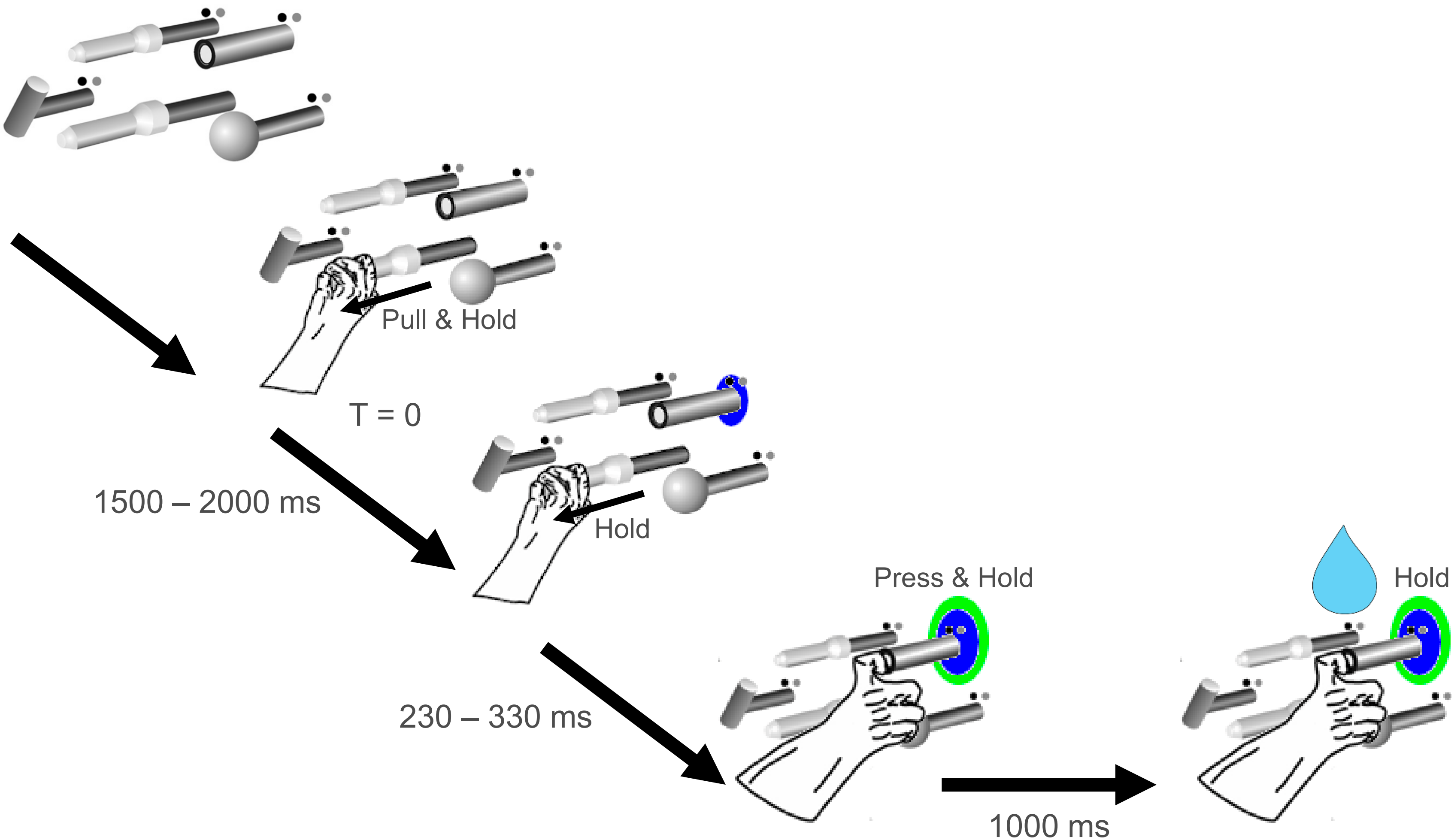

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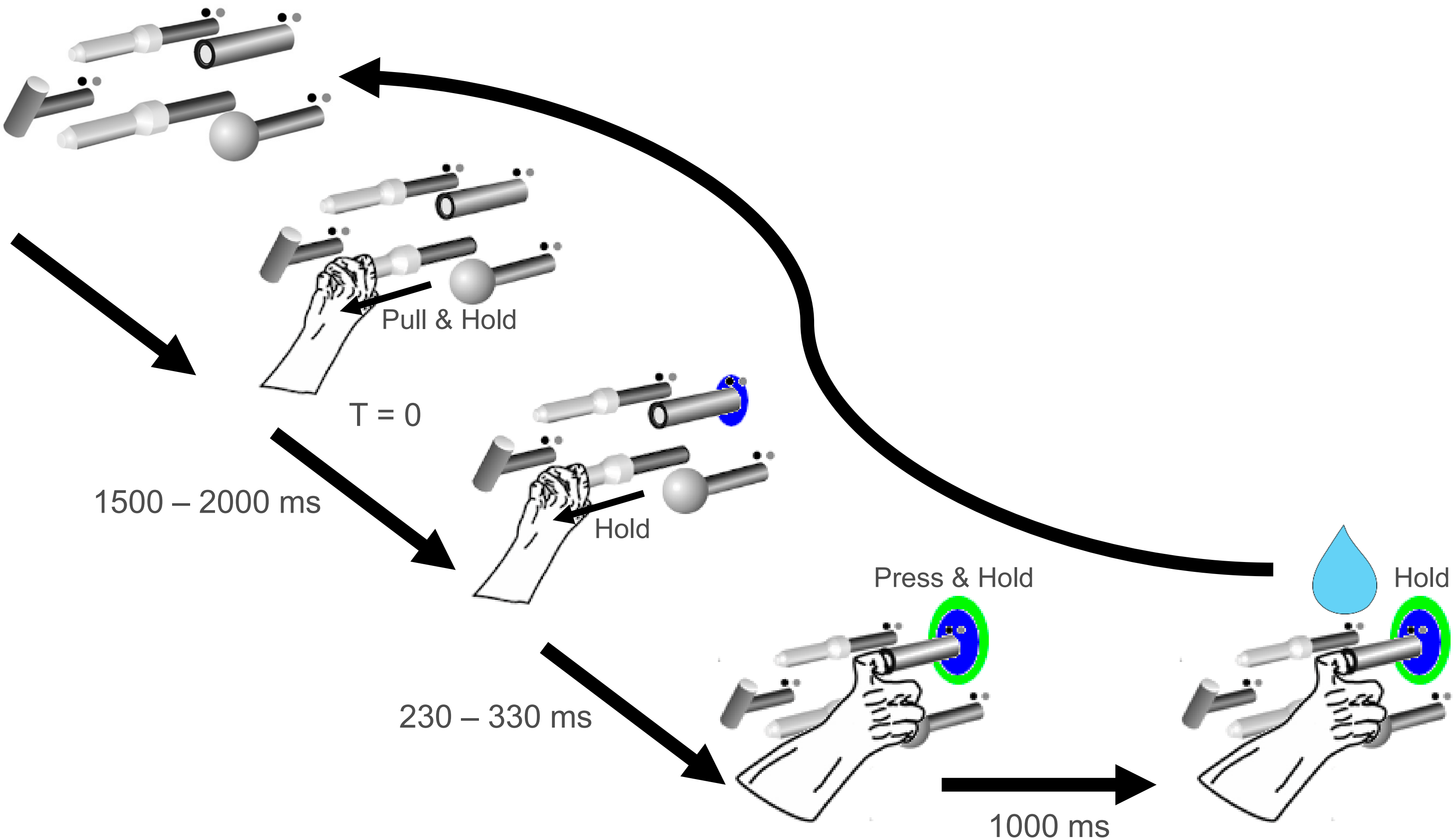

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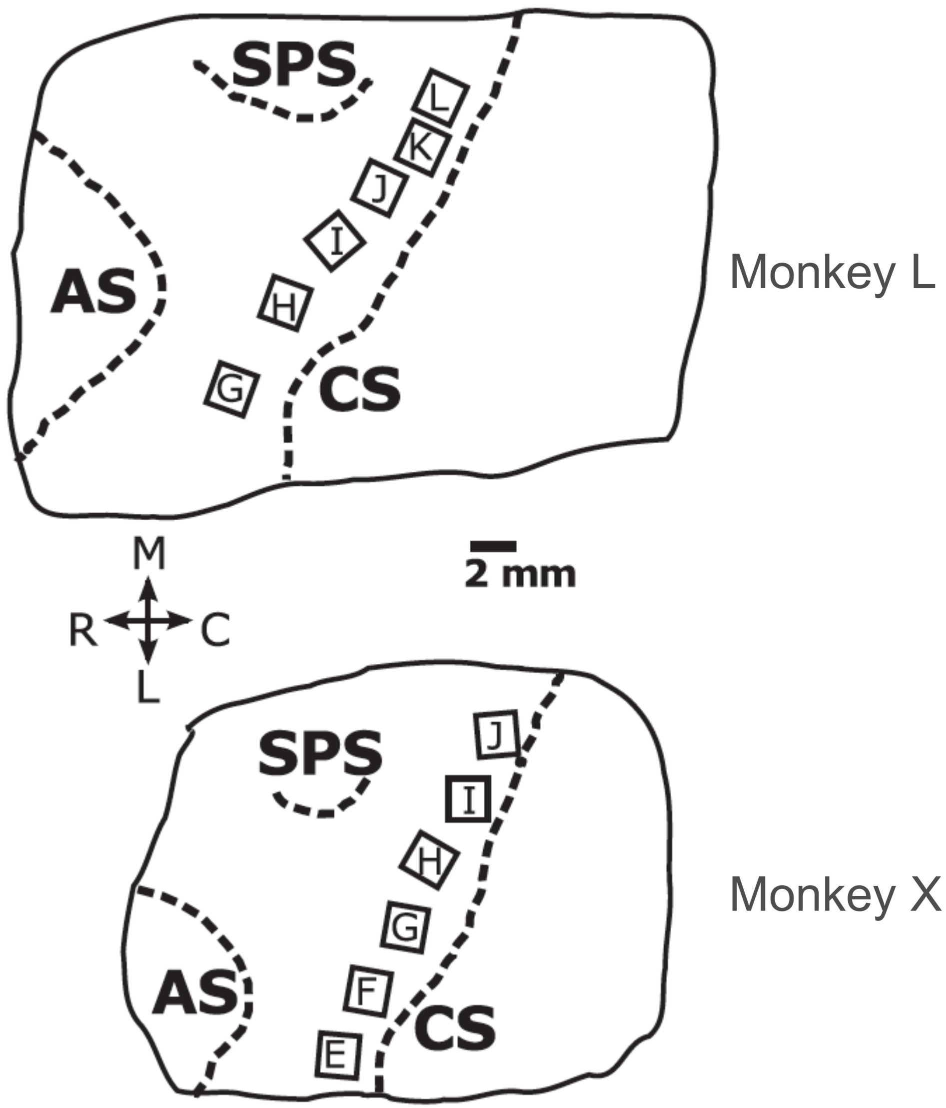
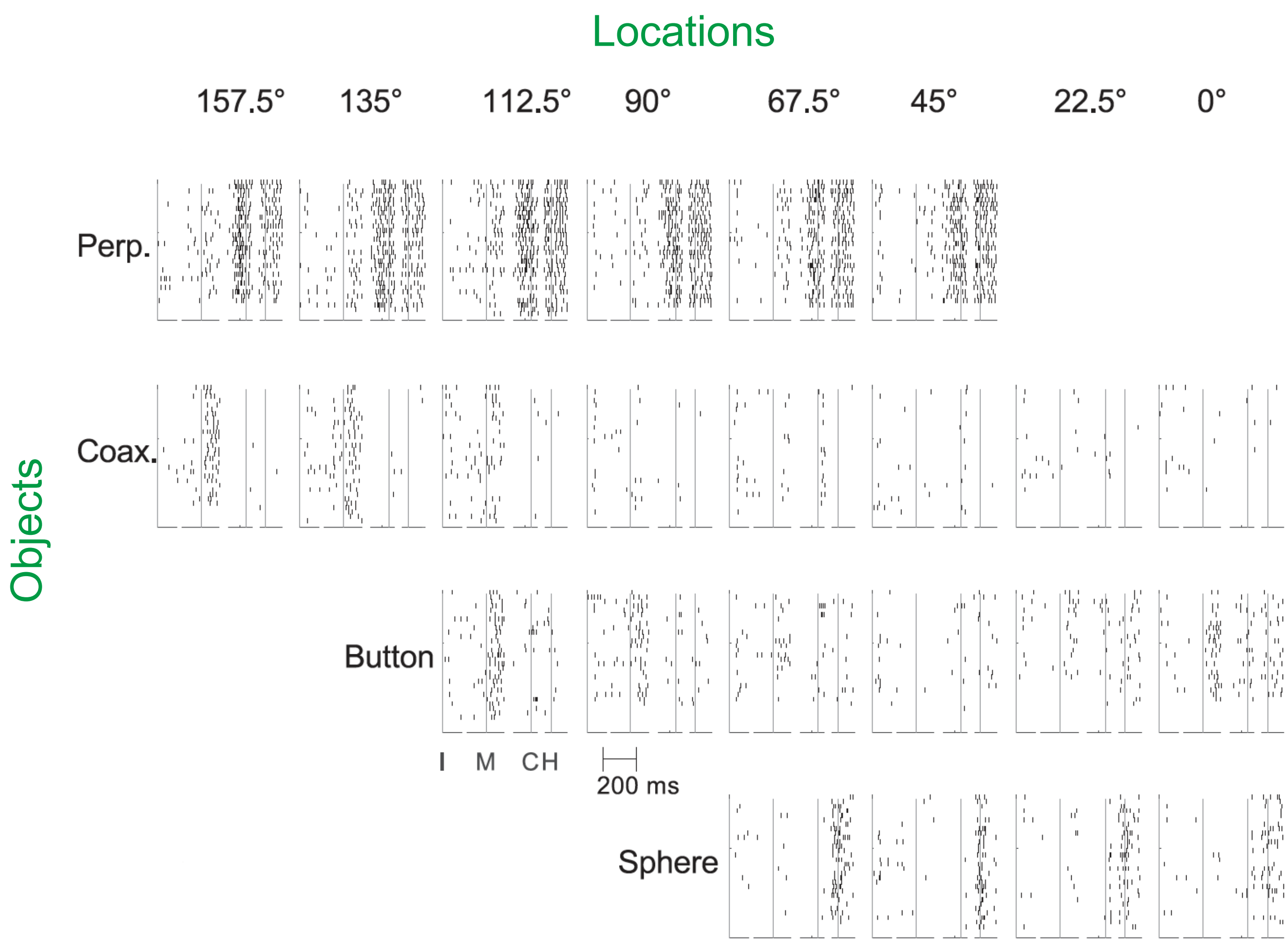
FMA Neural Recordings



Rouse & Schieber 2016 *J Neurosci.*

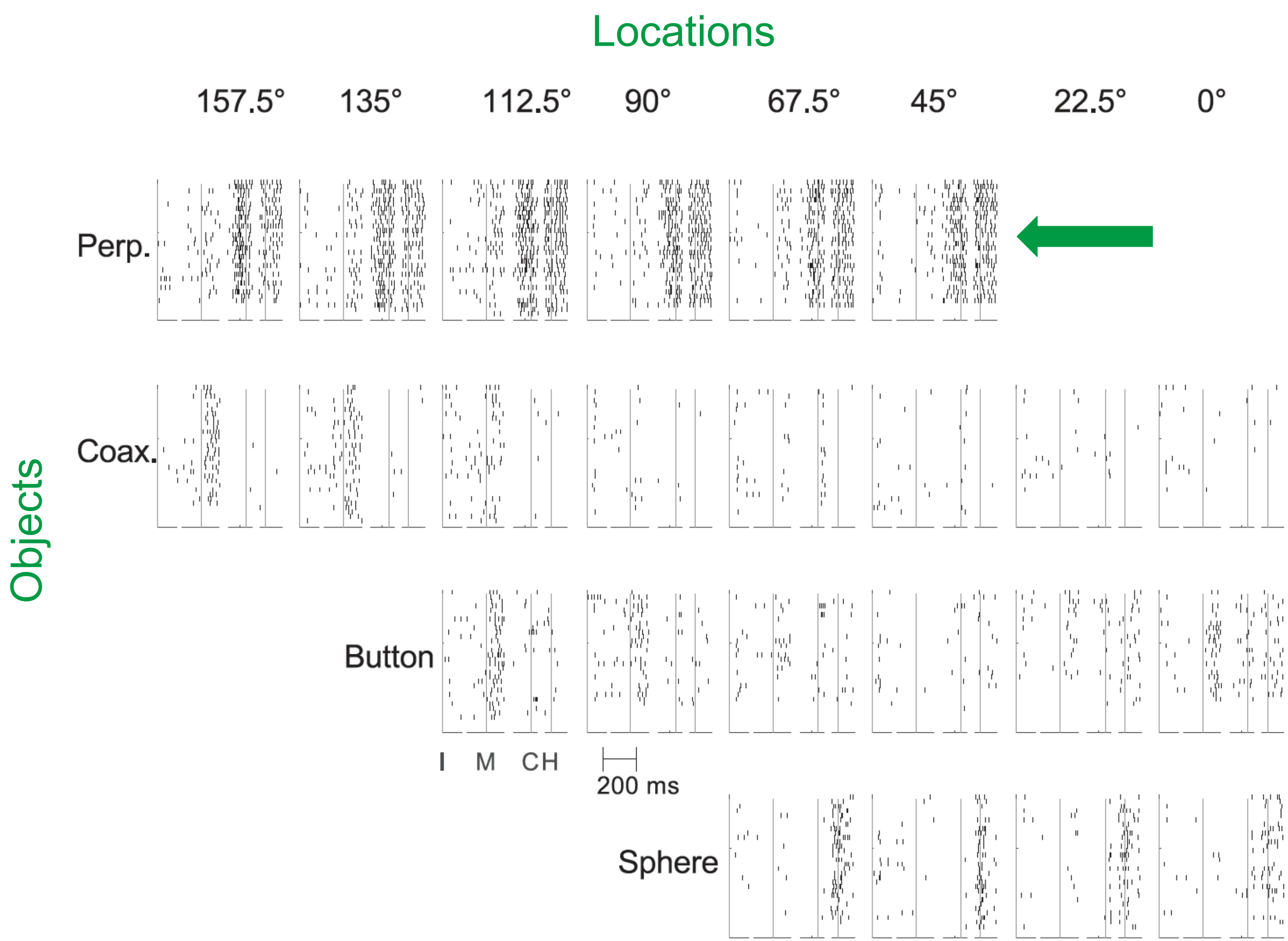
Analysis & Results

Typical neuron: mixed object-location effects



Rouse & Schieber 2016 *J Neurosci.*

Typical neuron: mixed object-location effects



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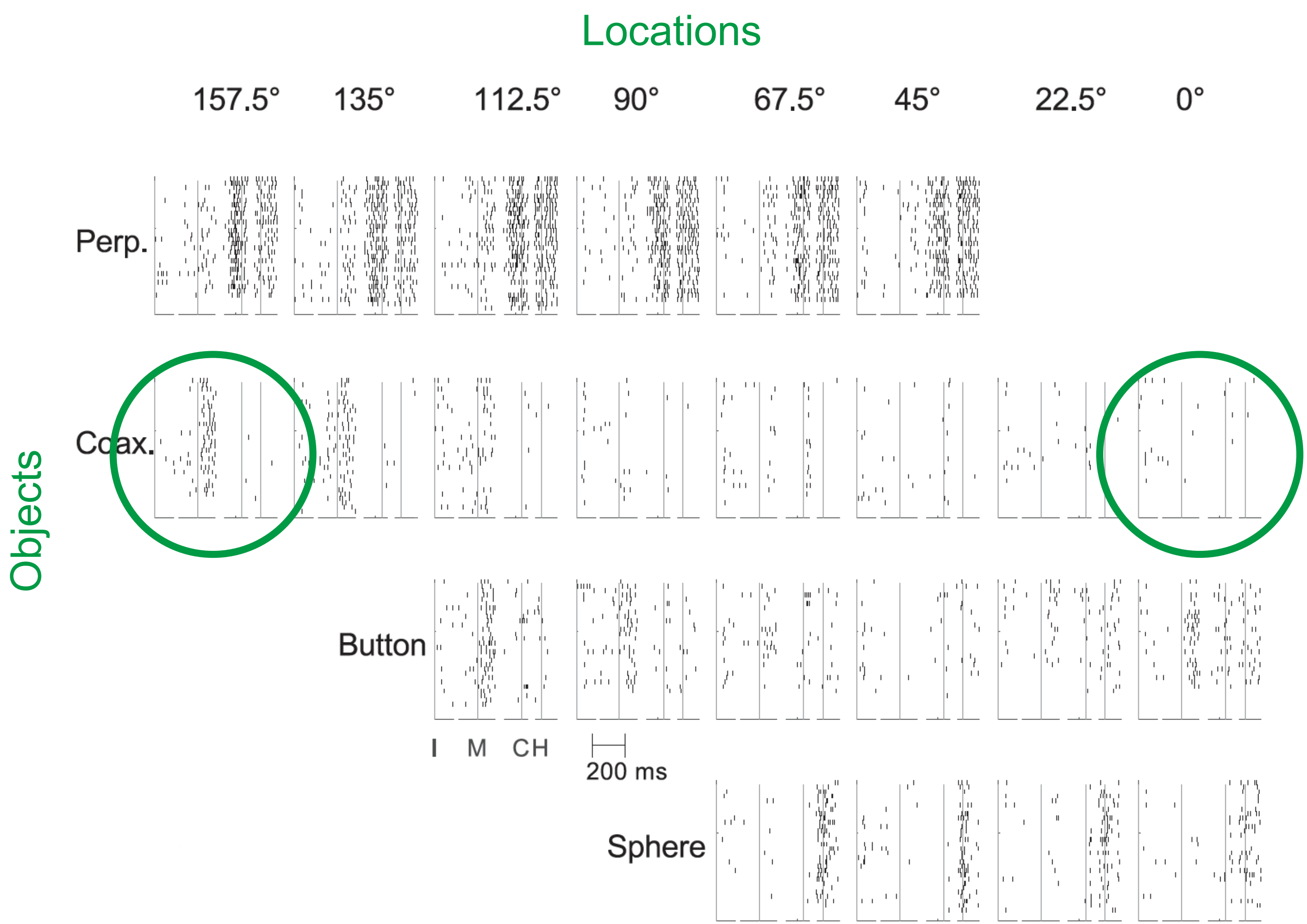

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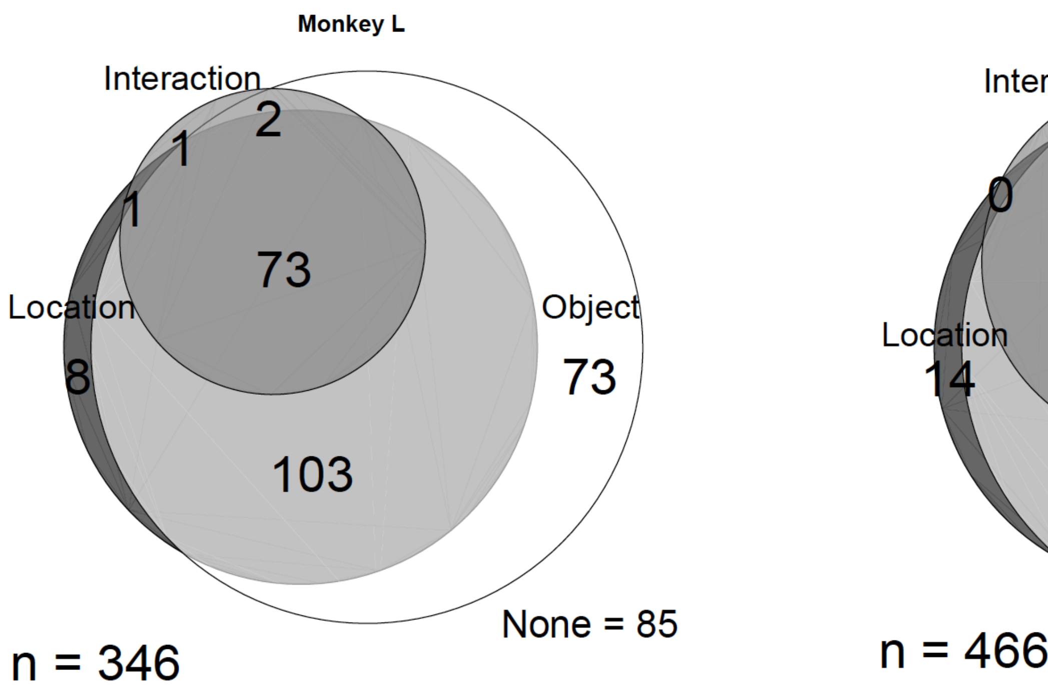
Most neurons have mixed “tuning”



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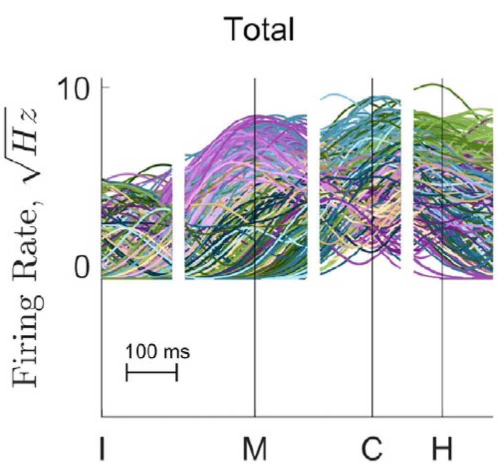
Variance Partitioning

Initiation

Movement Start

First **C**ontact

Beginning of **H**old



No subtraction

No averaging

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Variance Partitioning

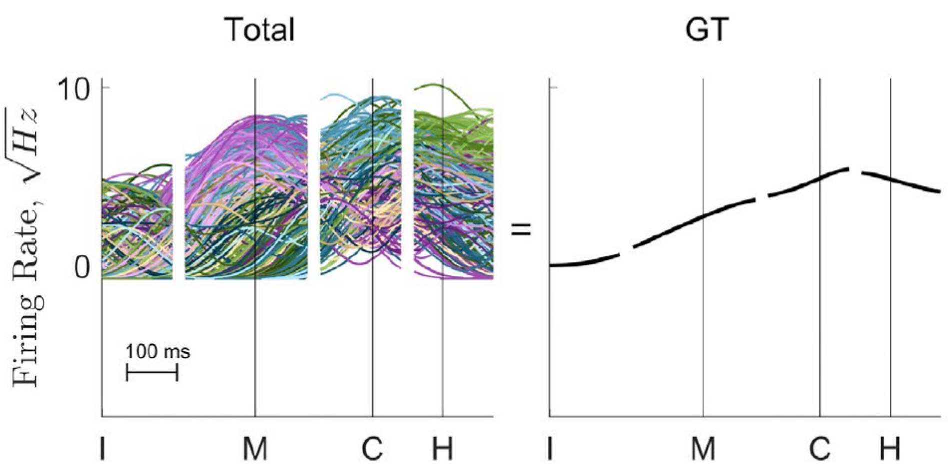
Initiation

Movement Start

First **C**ontact

Beginning of **H**old

General **T**ask



No subtraction

No subtraction

No averaging

Average across:

Trials & Conditions

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Variance Partitioning

Initiation

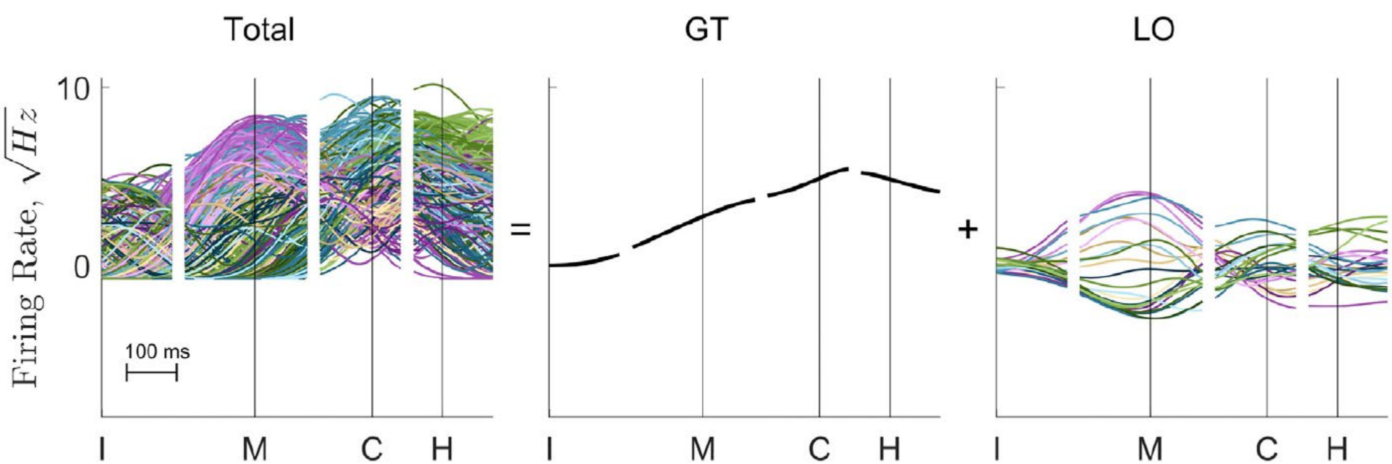
Movement Start

First **C**ontact

Beginning of **H**old

General **T**ask

Location / **O**bject



No subtraction | No subtraction | Subtract out: GT

No averaging | Average across: Trials & Conditions | Average across: Trials

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Variance Partitioning

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Movement Start

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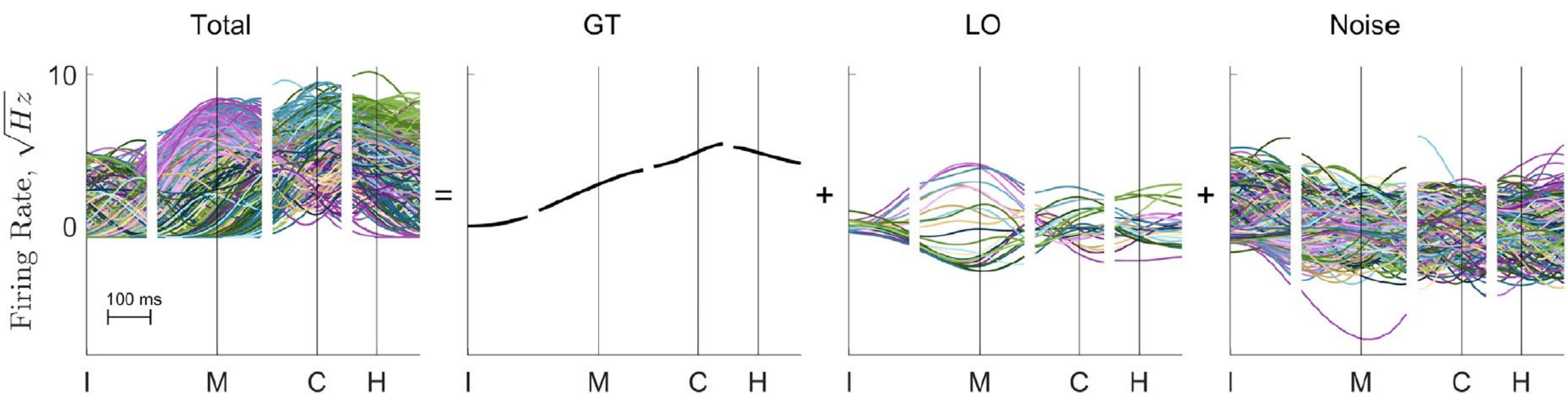

No subtraction	No subtraction	Subtract out:	Subtract out:
		GT	GT & LO
No averaging	Average across:	Average across:	No averaging
	Trials & Conditions	Trials	

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Variance Partitioning

Initial Partitioning versus Demixing: Implications for Overlap of Subspaces

In contrast to the recently developed approach of demixed PCA (dPCA), which identifies PCs that best transform the original data to reconstruct different partitions of the neural activity (Brendel et al., 2011; Kobak et al., 2016), we chose to partition the data first and then perform standard PCA on each partition separately. Because any dimension of the neural space may have variance in more than one partition, dPCA may not always identify the highest variance PCs in a given partition if those PCs also include variance from other partitions. While dPCA may improve visualization, our present approach was designed to quantify the magnitude and dimensionality of neural activity in each partition separately, as well as the overlap between partitions. We also performed dPCA on our dataset with qualitatively similar results (not illustrated). The demixed PCs were

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Variance of each component over time

Initiation

Movement Start

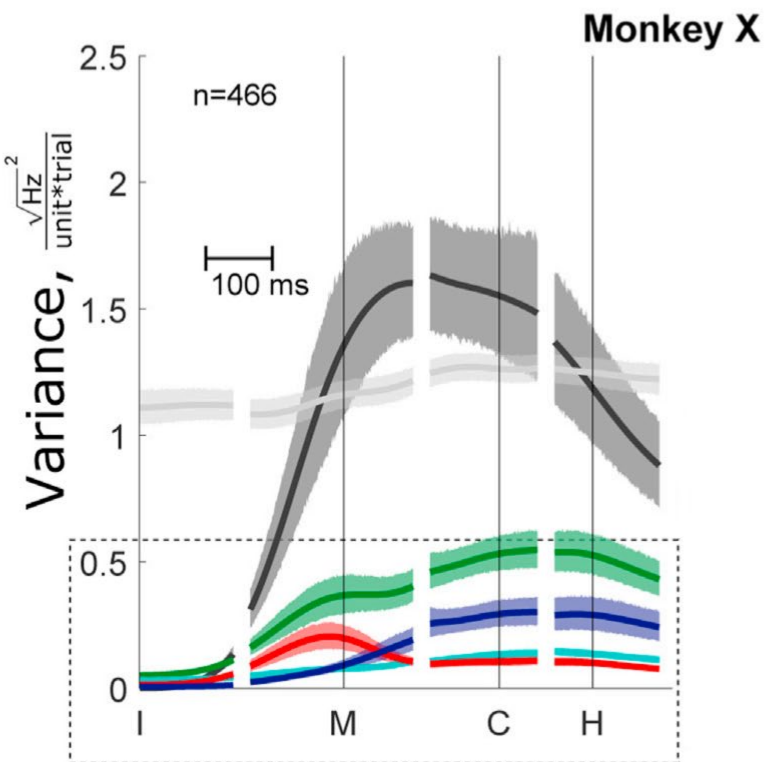
First **C**ontact

Beginning of **H**old

General Task

Location / Object → Location, Object, Interaction

Noise



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Variance of each component over time

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General Task

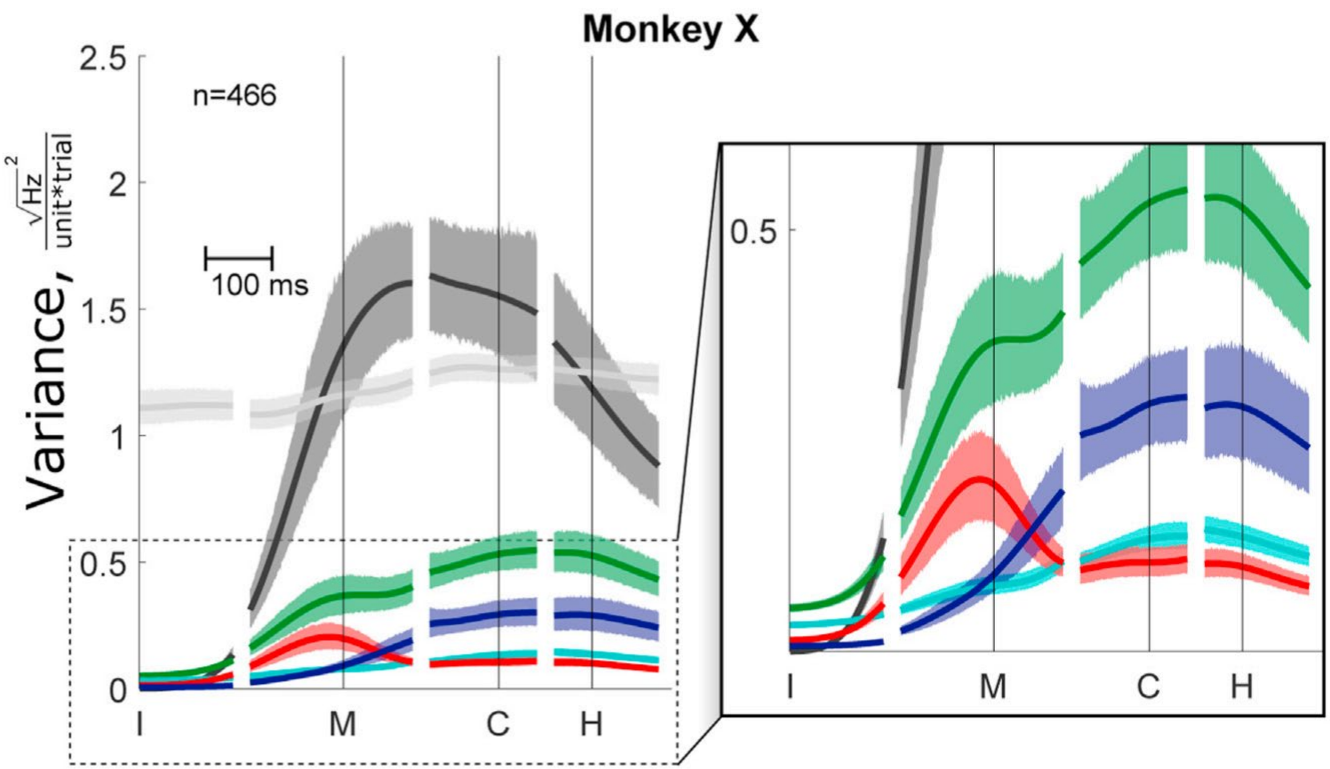
Location / Object

Noise

Location

Object

Interaction



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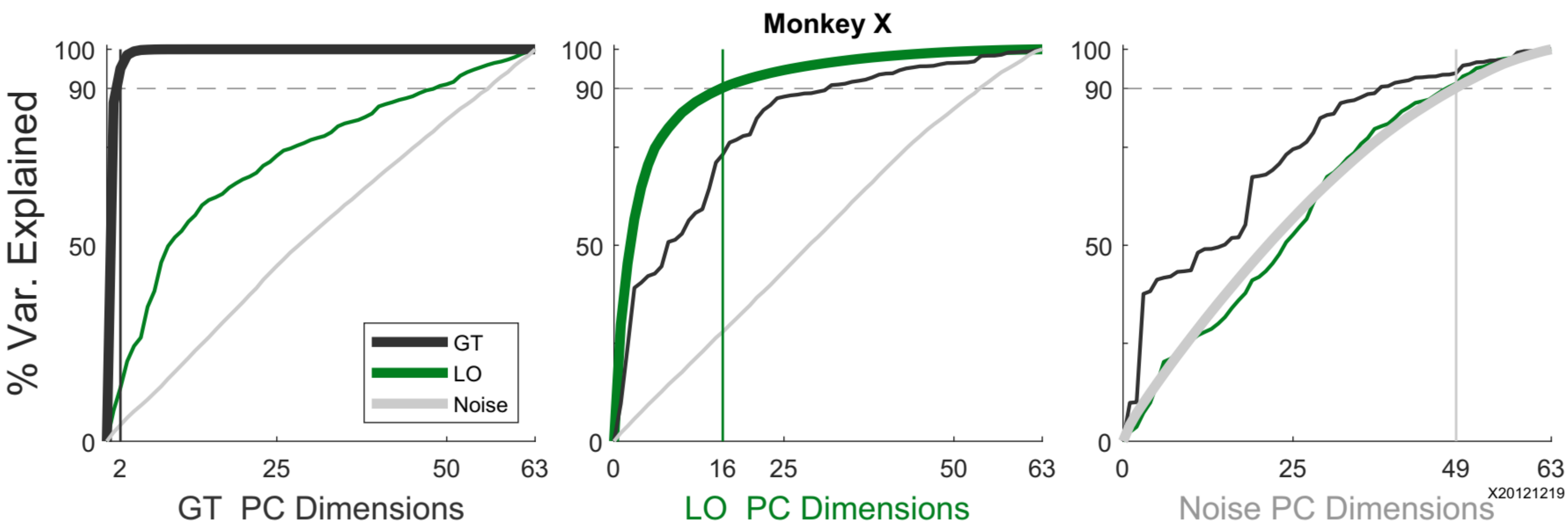
Overlap between subspaces



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Overlap between subspaces quantified

$$Overlap = \frac{tr(\Sigma_1 \Sigma_2)}{\|\Sigma_1\|_F \cdot \|\Sigma_2\|_F}$$

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Null distribution bootstrapping:

$$\Sigma_1$$

$$d \times d$$

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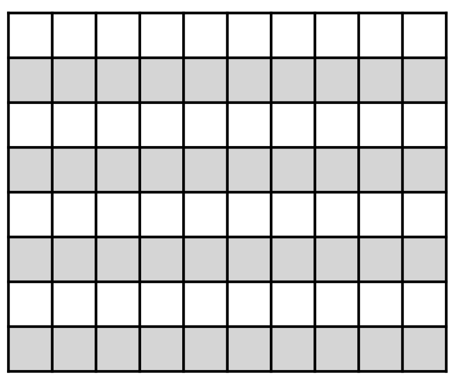

$$24 \times d$$

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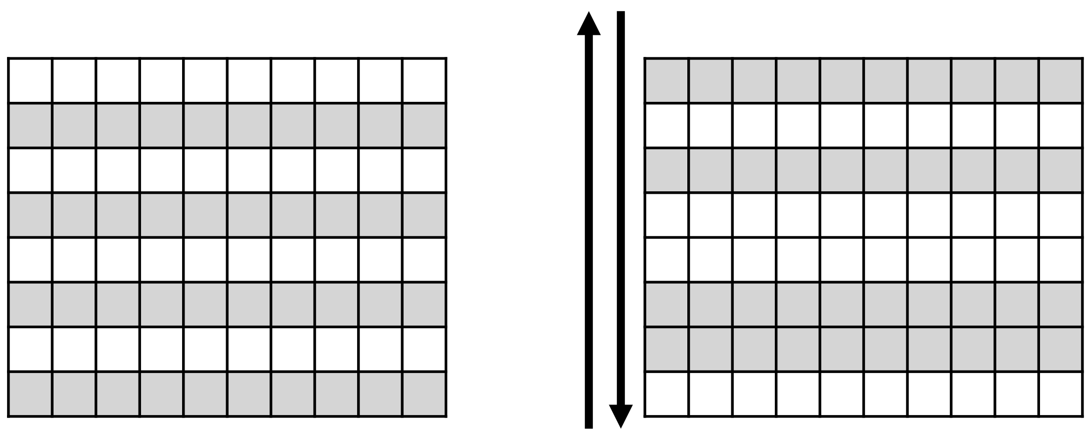

$24 \times d$ $24 \times d$

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Overlap between subspaces quantified

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Null distribution bootstrapping:

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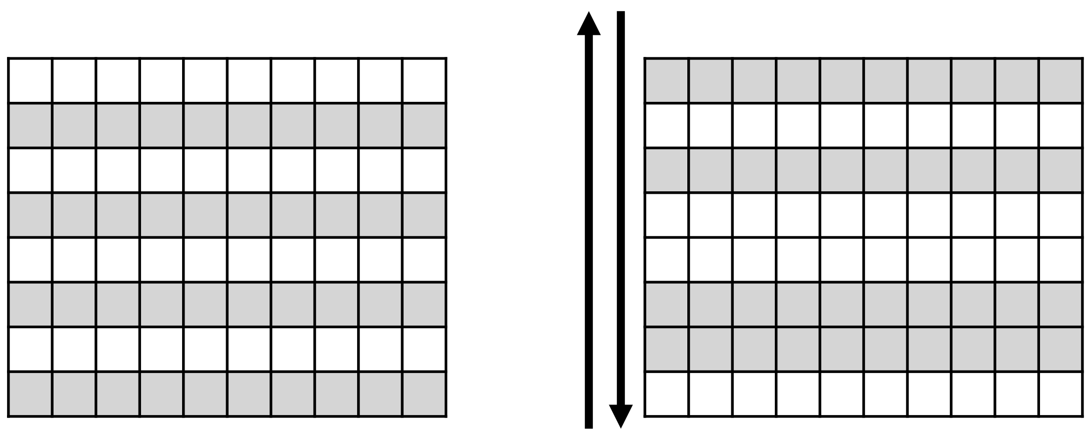
$d \times d$



$24 \times d$ $\qquad$ $24 \times d$

Σ_2

$d \times d$

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Overlap between subspaces quantified

$$Overlap = \frac{tr(\Sigma_1 \Sigma_2)}{\|\Sigma_1\|_F \cdot \|\Sigma_2\|_F}$$

Data (95% CI of Null):

GT vs LO:	GT vs Noise:	LO vs Noise:
L: 0.26 (0.02 – 0.18)	L: 0.18 (0.11 – 0.17)	L: 0.29 (0.20 – 0.29)
X: 0.26 (0.02 – 0.20)	X: 0.24 (0.15 – 0.21)	X: 0.36 (0.26 – 0.33)

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X: 0.26 (0.02 – 0.20)	X: 0.24 (0.15 – 0.21)	X: 0.36 (0.26 – 0.33)

Not 0!

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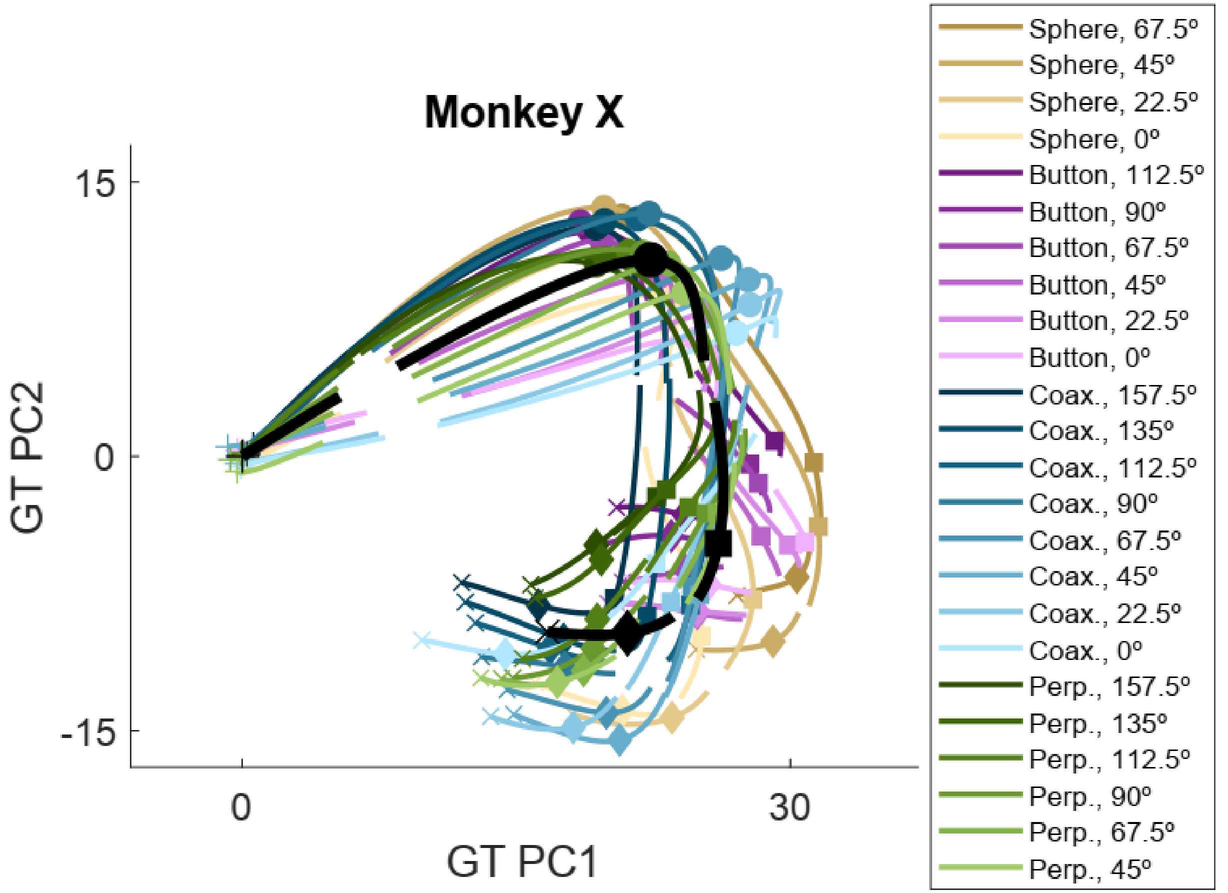
Projections onto GT subspace



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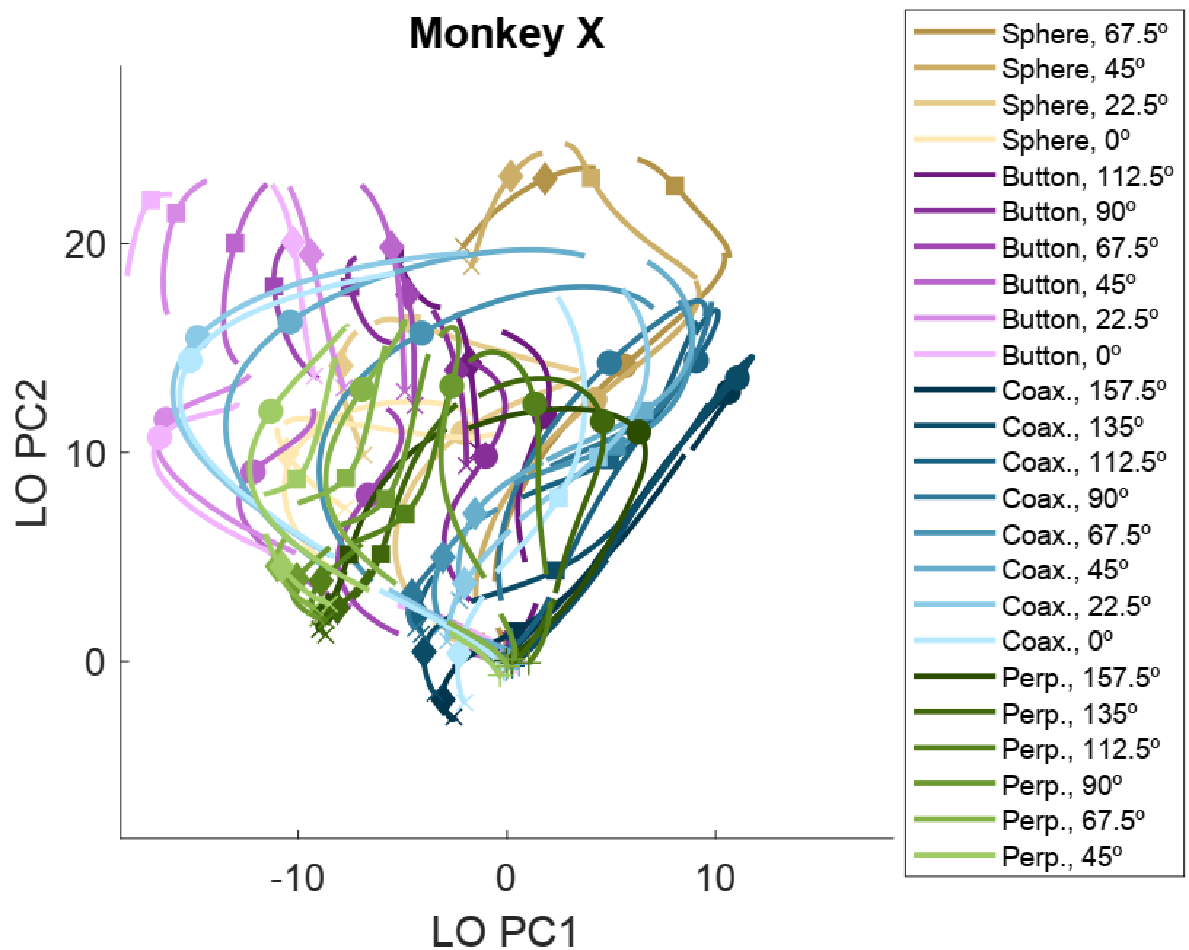
Projections onto LO subspace



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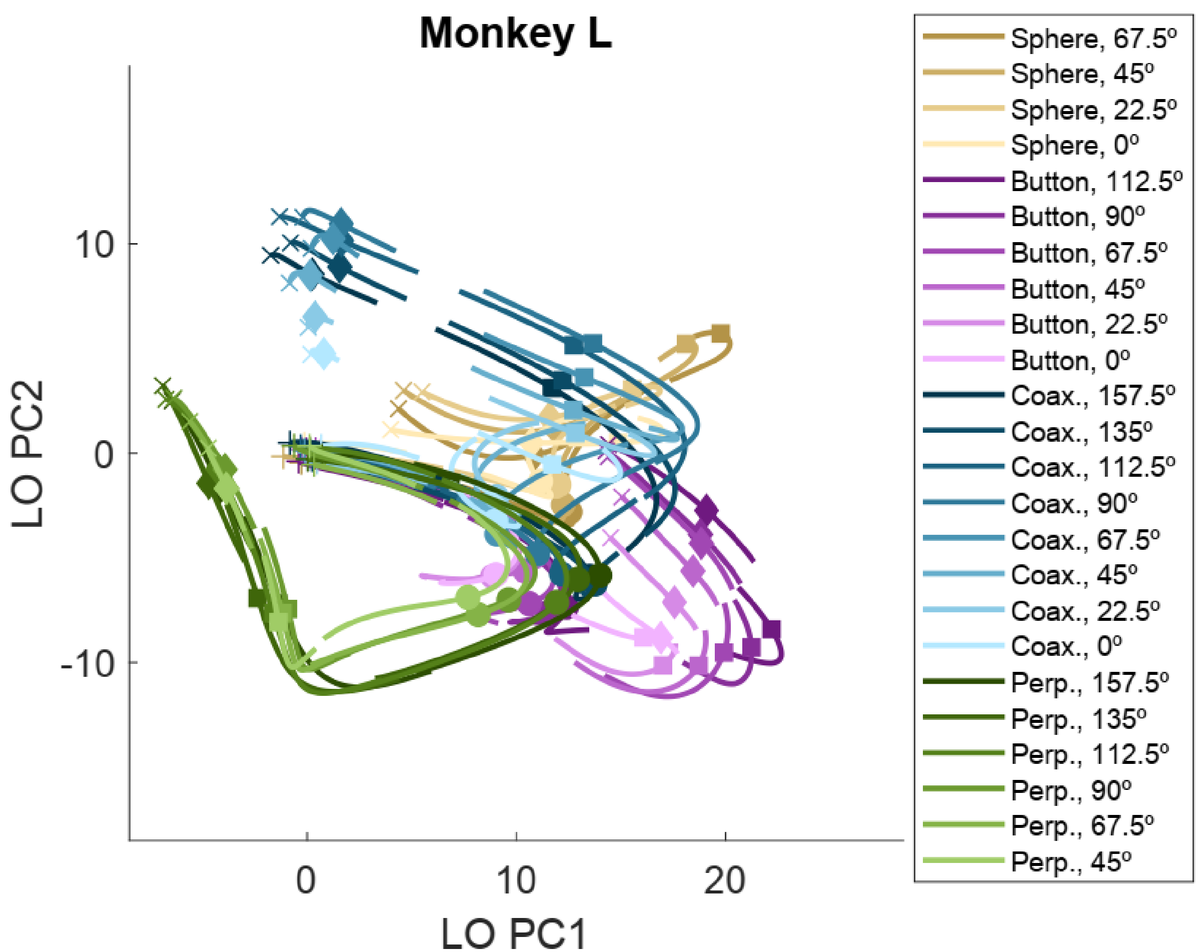
Projections onto LO subspace



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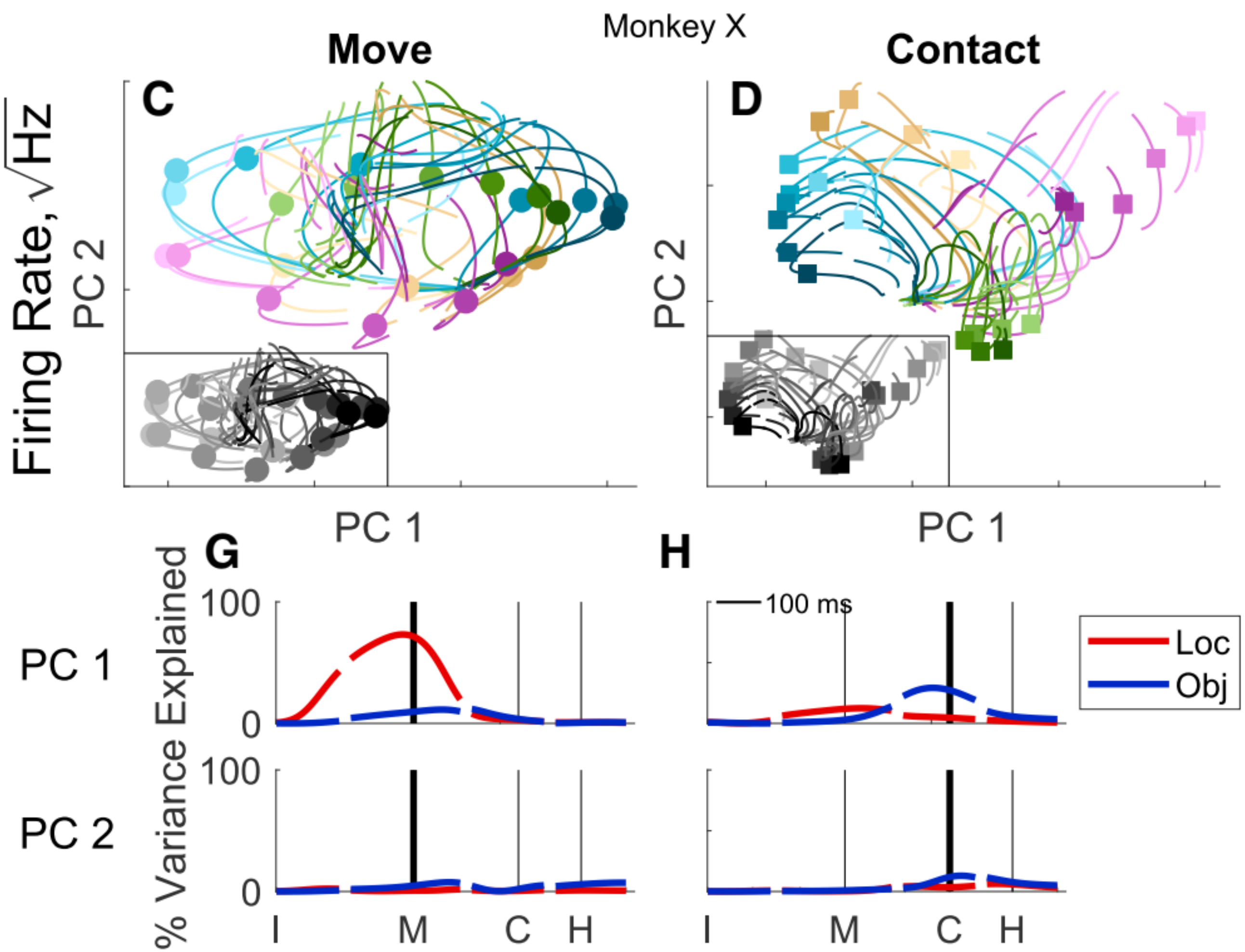
Separate PCA for different alignments



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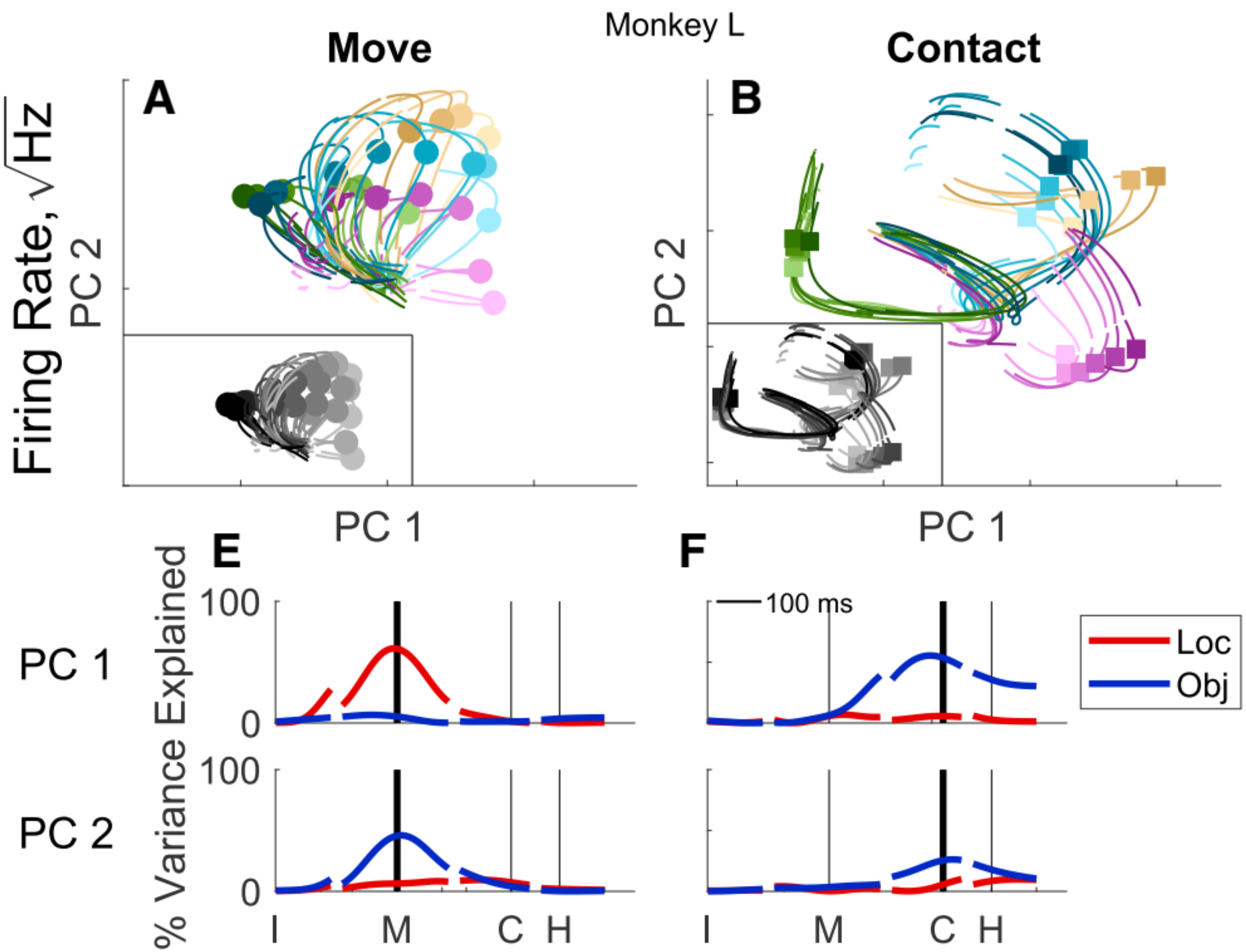

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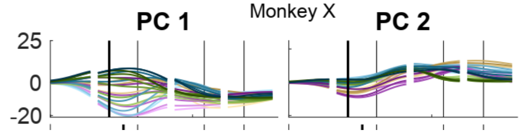
Even *more* time-specific PCA!



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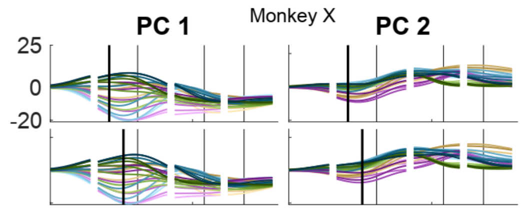

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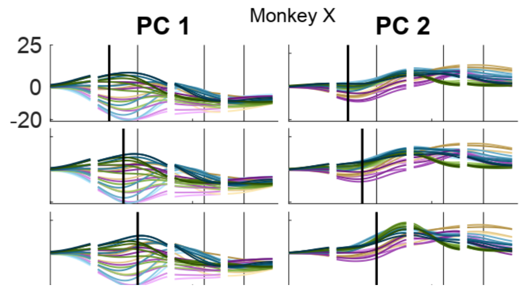

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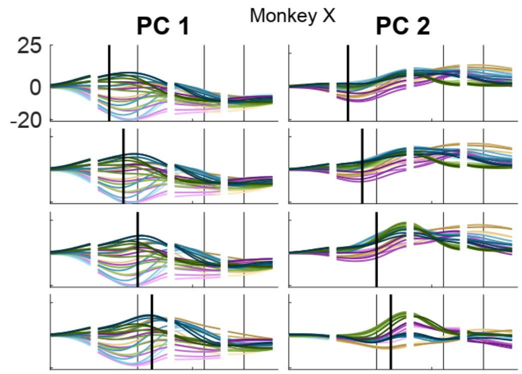

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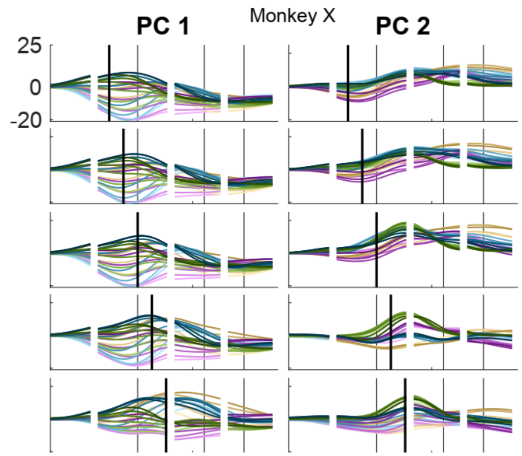

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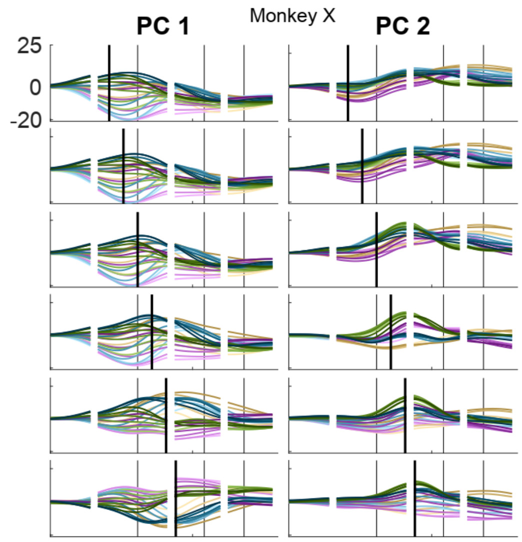

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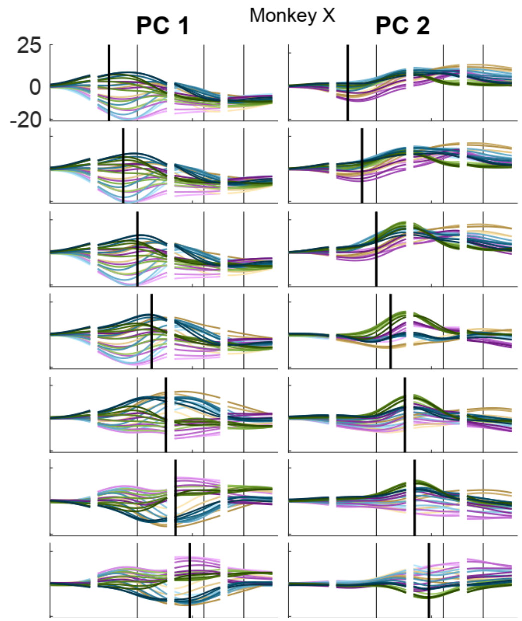

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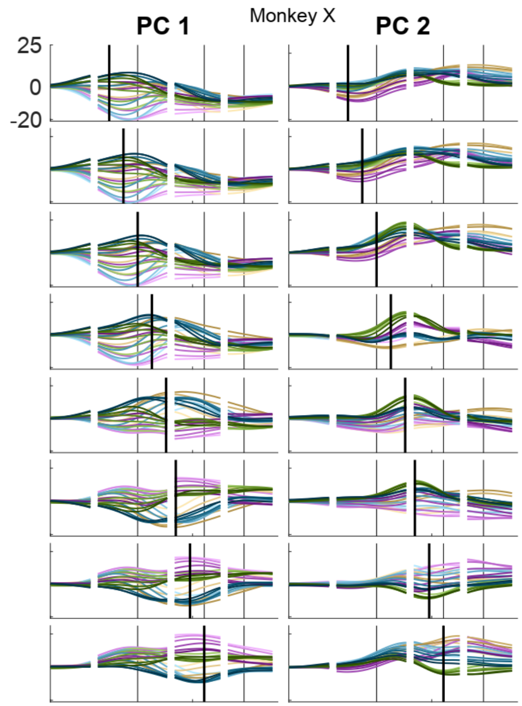

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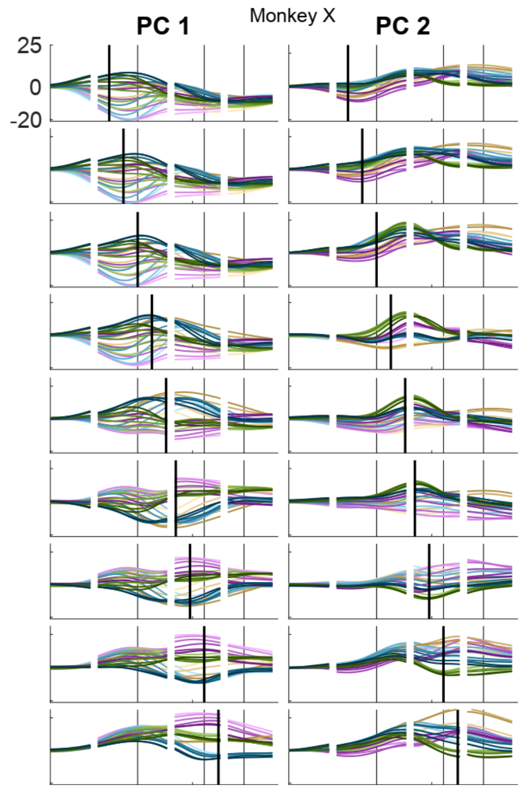

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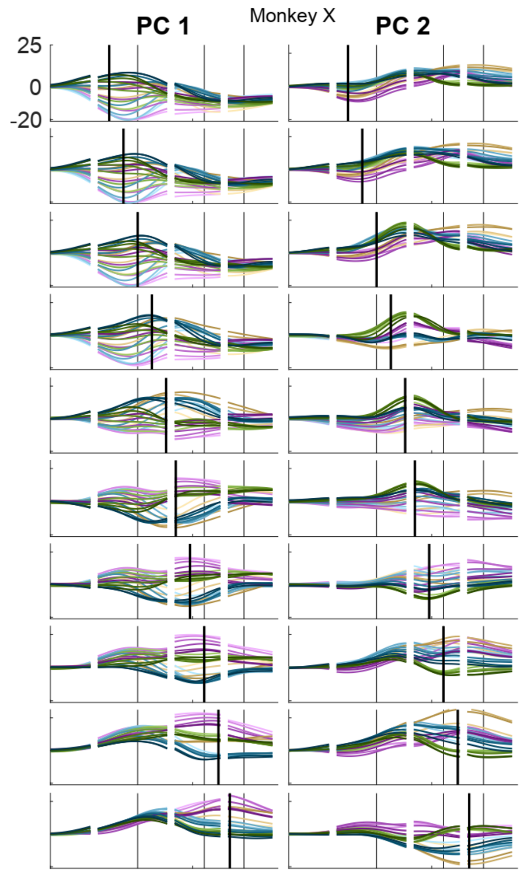

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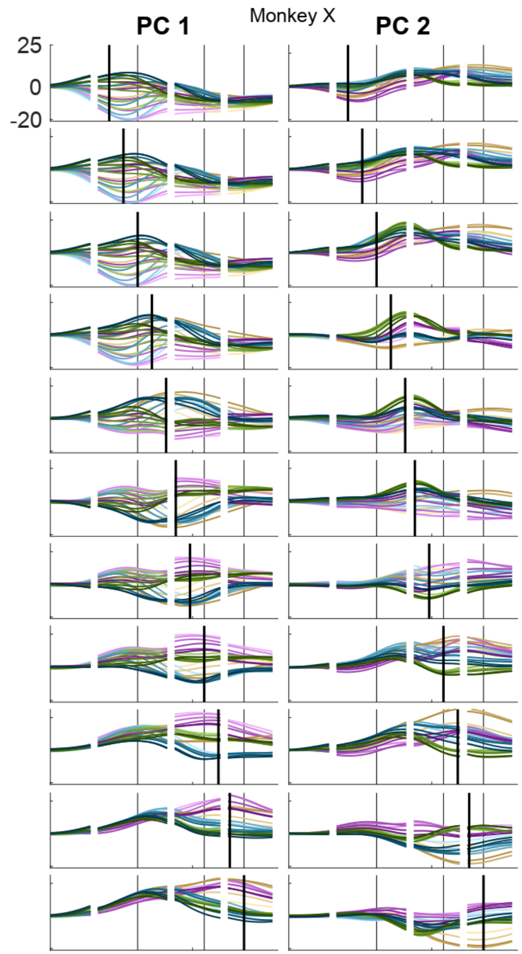

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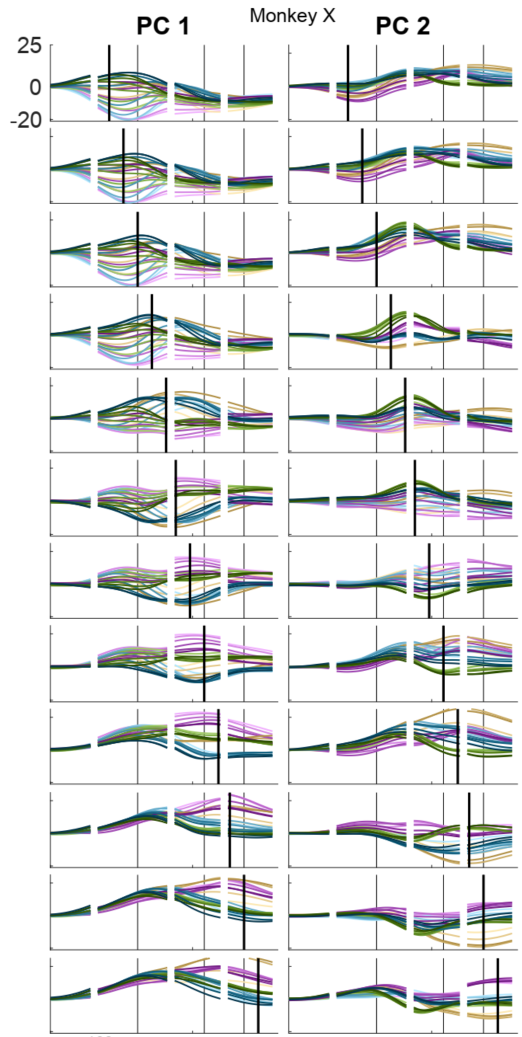

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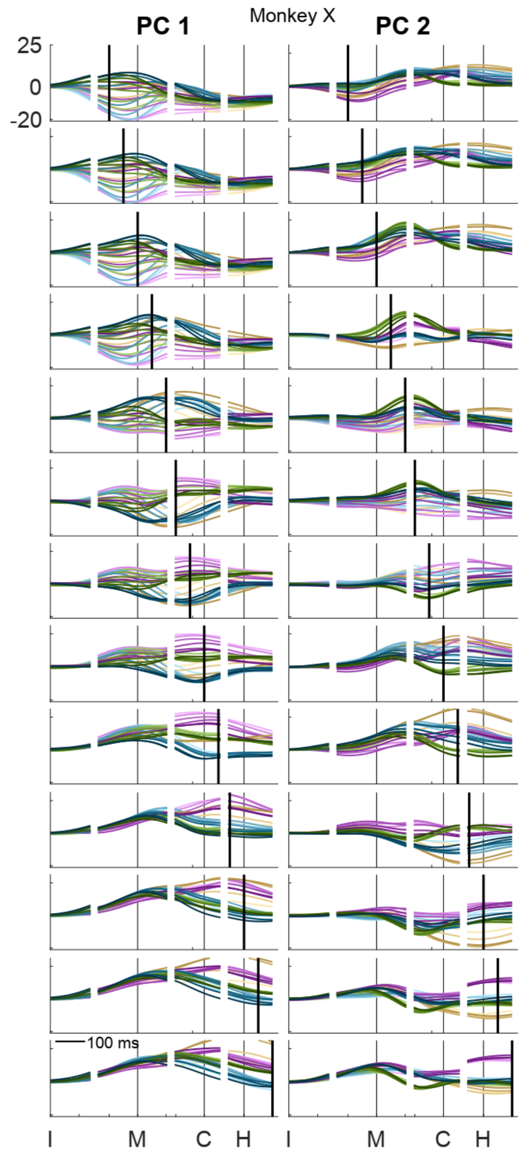

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Overlap between time-specific PCAs

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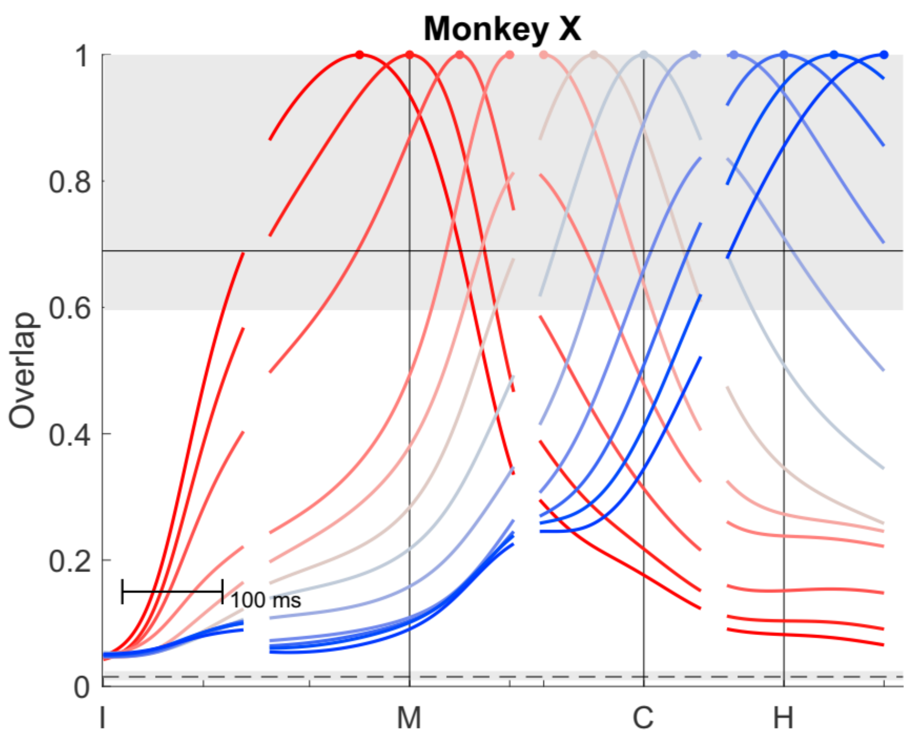

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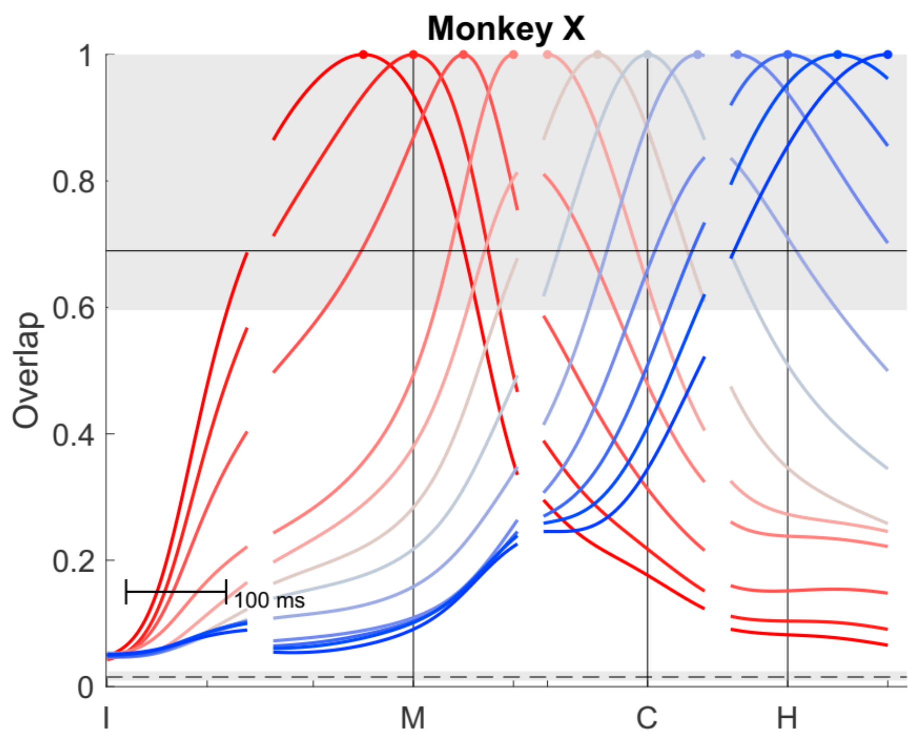

95% CI if sampled from *same* subspace

95% CI if sampled from *shuffled* subspaces

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Conclusions

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- Mixed selectivity in individual M1 neurons

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- Separation of location & object only at the population level
  - No spatial organization
  - Separation != orthogonal
- Over time, neural activity gradually transitions
  - From location-specific (“reach”) subspace
  - To object-specific (“grasp & manipulate”) subspace

Epilogue

Whence comes this transition?

Rotational dynamics?

- Single rotational plane during reaching

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Rotational dynamics?

- Single rotational plane during reaching
  - Captures gradual transition from preparation to movement

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Rouse & Schieber 2018 *Cell Reports*

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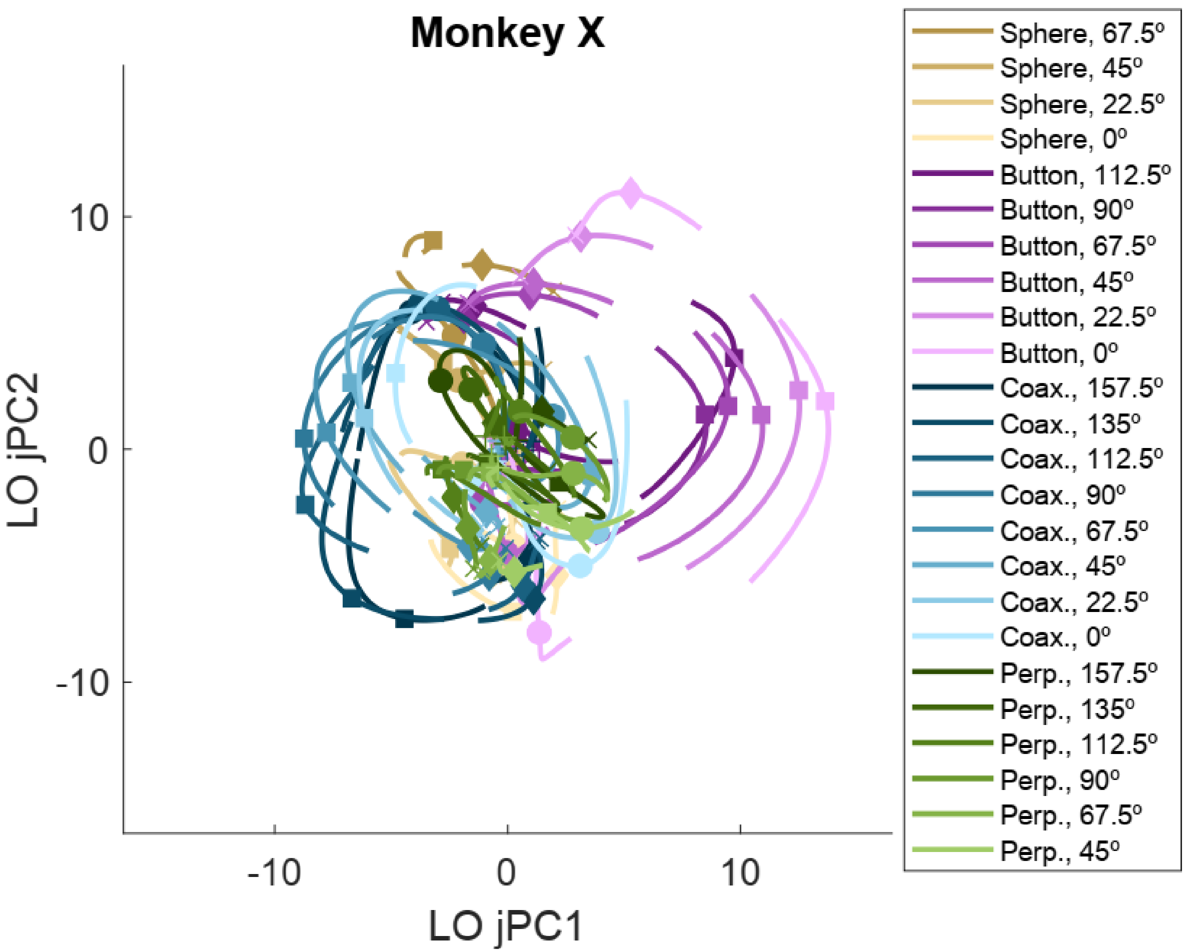

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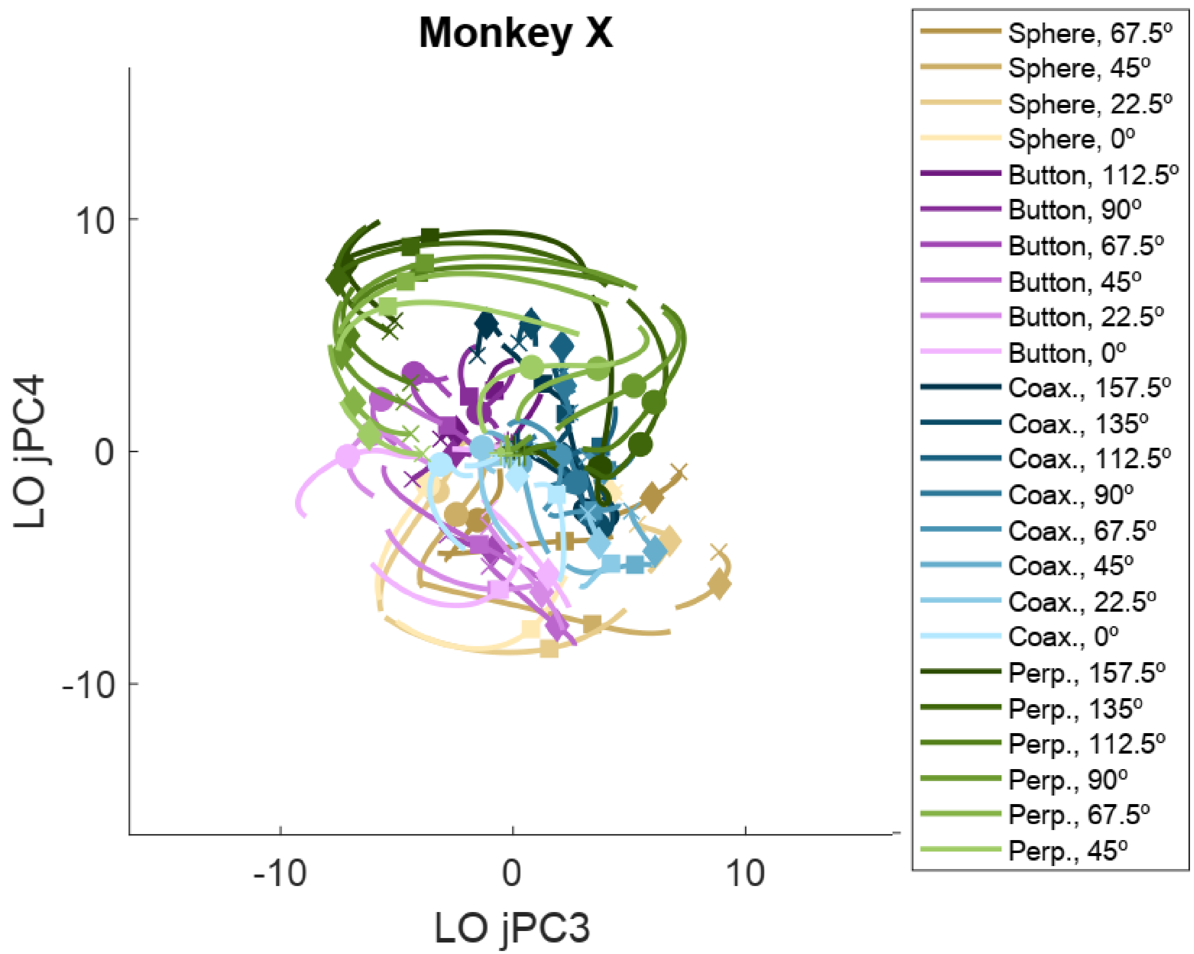

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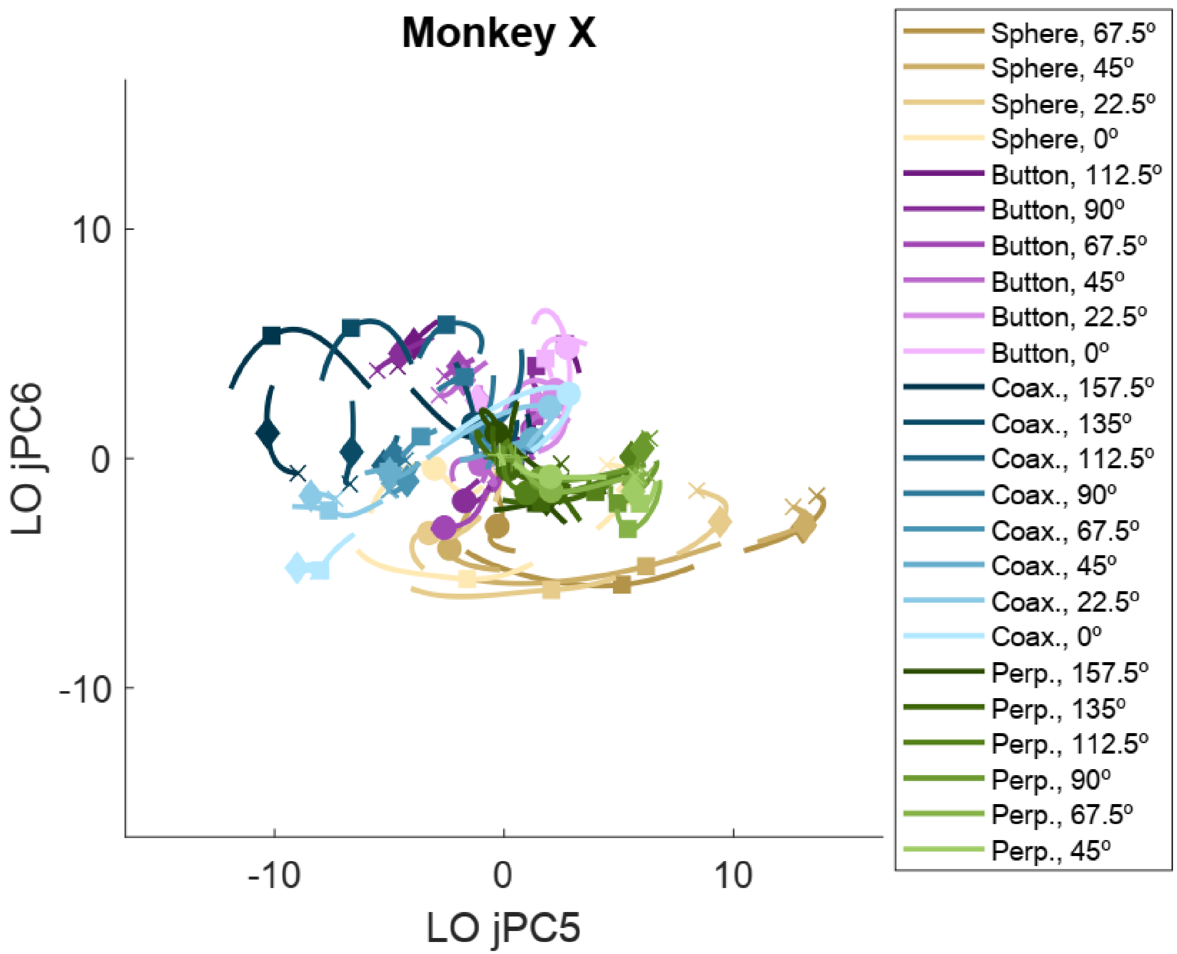

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- Can this also account for transition from reach to grasp?
  - **No**: one plane cannot explain it all
  - Rotations occupy different dimensions depending on the object

Rouse & Schieber 2018 *Cell Reports*

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FIN

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