Cortical activity in the null space: permitting preparation without movement

Kaufman, Churchland, Ryu, & Shenoy

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NEU 560, Lecture 6 part I
(PCA and regression applications)

Jonathan Pillow

but first: subspaces!

Neural Variability in Premotor Cortex Provides a Signature of Motor Preparation

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J Neurosci 2006

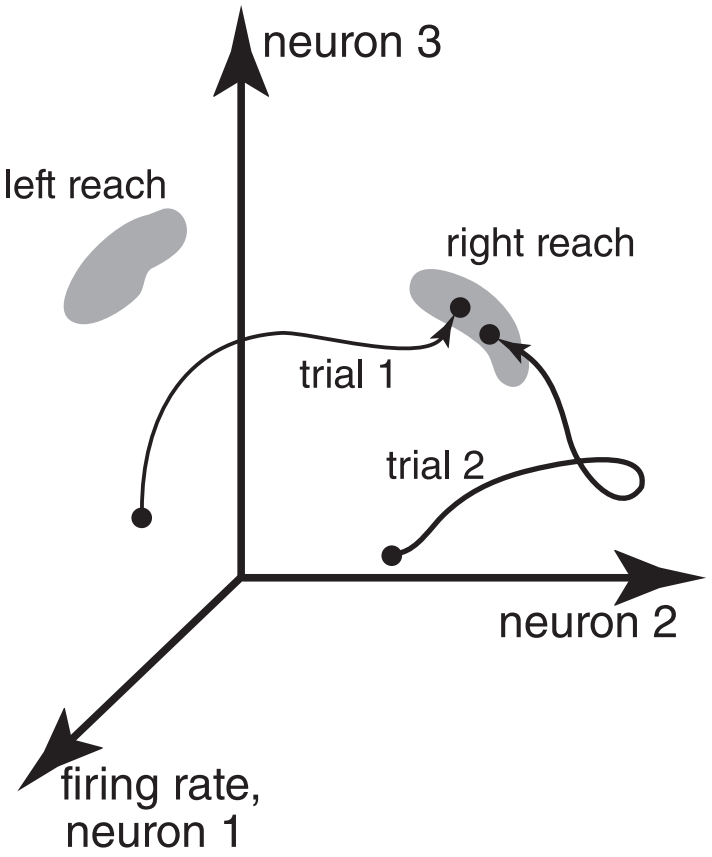
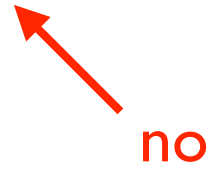


Figure 1. Illustration of the optimal-subspace hypothesis. The configuration of firing rates is represented in a state space, with the firing rate of each neuron contributing an axis, only three of which are drawn. For each possible movement, we hypothesize that there exists a subspace of states that are optimal in the sense that they will produce the desired result when the movement is triggered. Different movements will have different optimal subspaces (shaded areas). The goal of motor preparation would be to optimize the configuration of firing rates so that it lies within the optimal subspace for the desired movement. For different trials (arrows), this process may take place at different rates, along different paths, and from different starting points.

Motivation:

- how can we plan a course of action, while still waiting for the right moment to act?
- preparatory activity occurs in motor cortex prior to a movement; why doesn't it *cause* movement? (sub-threshold? gating?)



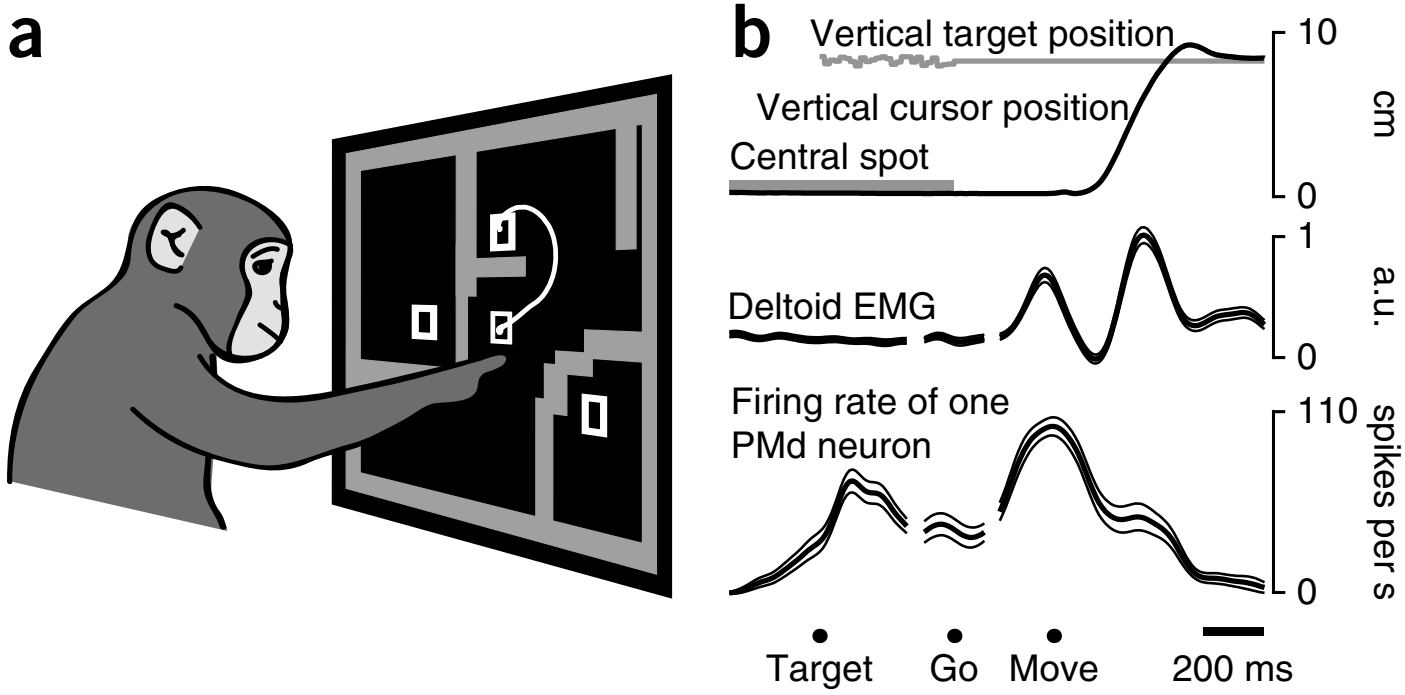
- new proposed mechanism: linear algebra!

Methods:

- multi-electrode recordings:
  - dorsal premotor cortex (PMd)
  - primary motor cortex (M1)
- behavior: monkey cued about upcoming movement
- preparatory activity: predicts aspects of movement (reaction time, variability, etc)

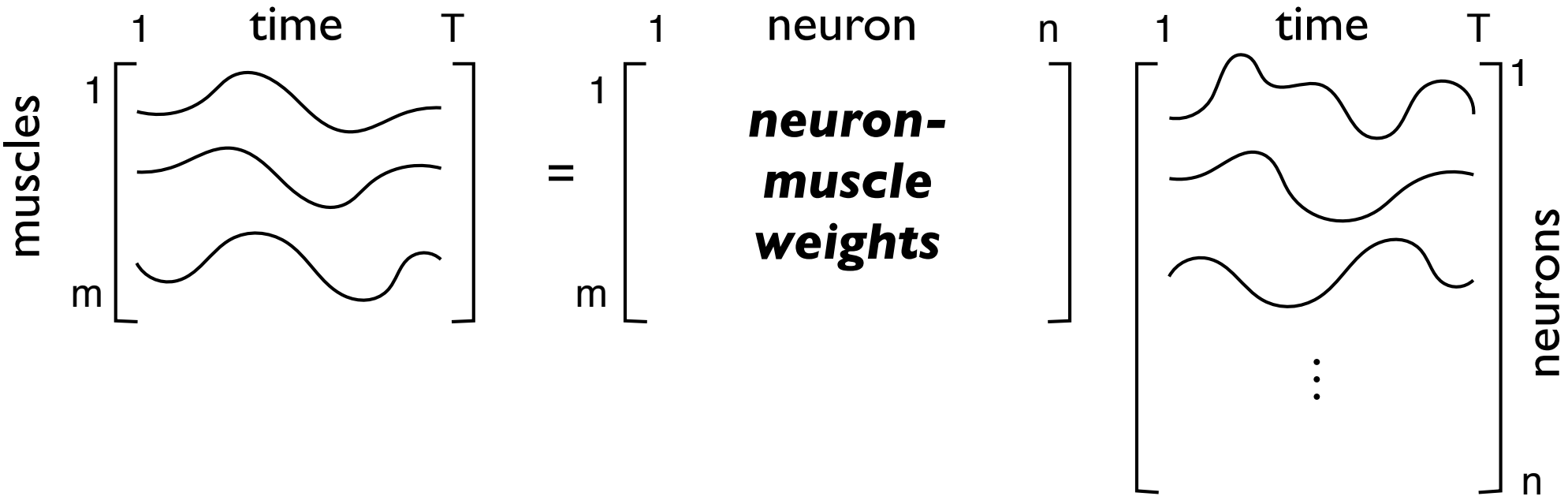
Fig 1

task and typical data



Model: regression!

$$M = WN$$

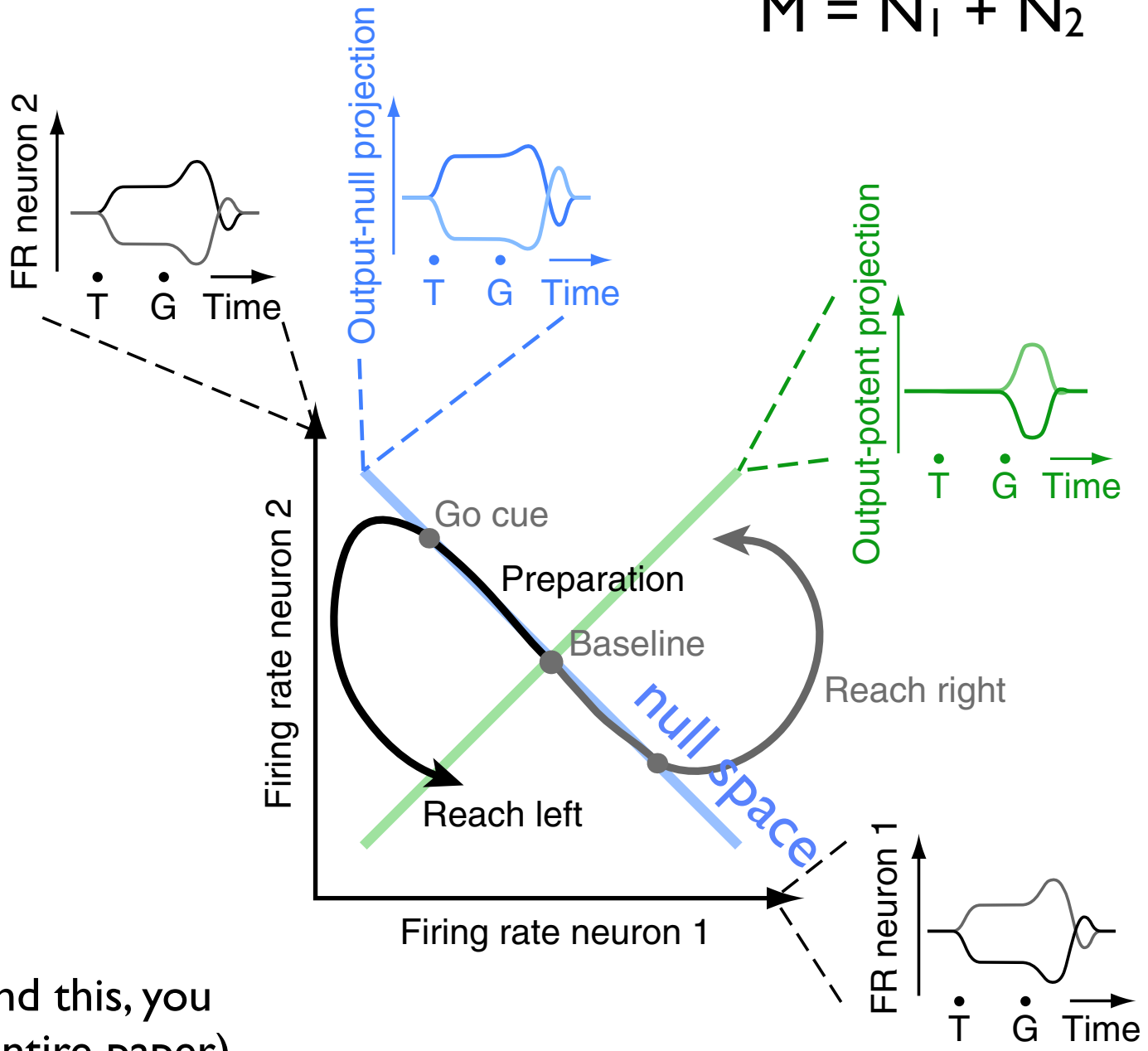


- basic idea: neural activity patterns orthogonal to the row space of W won't affect the muscles

Fig 2

toy example: muscle force proportional to sum of two neural inputs

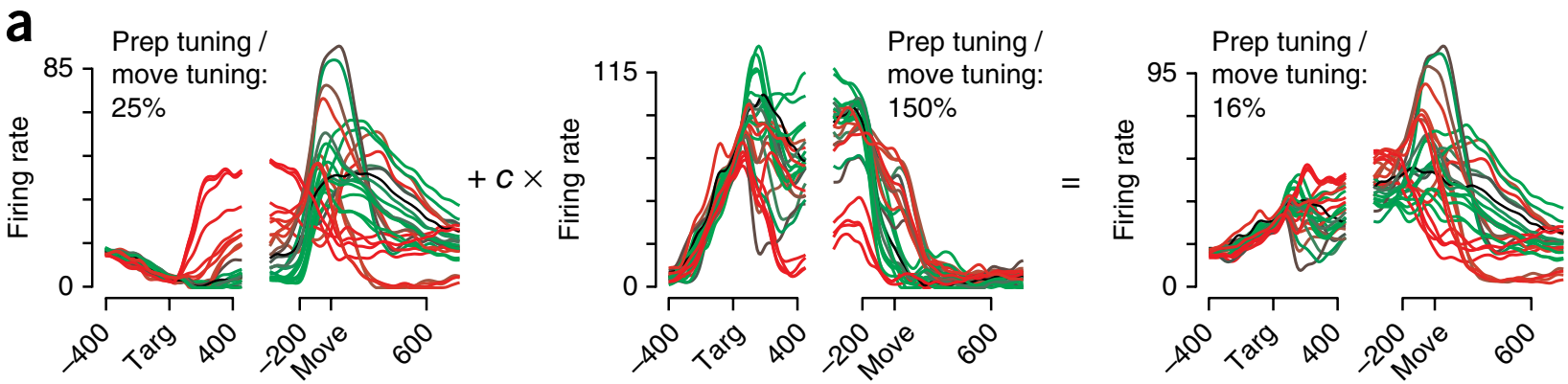
$$M = N_1 + N_2$$



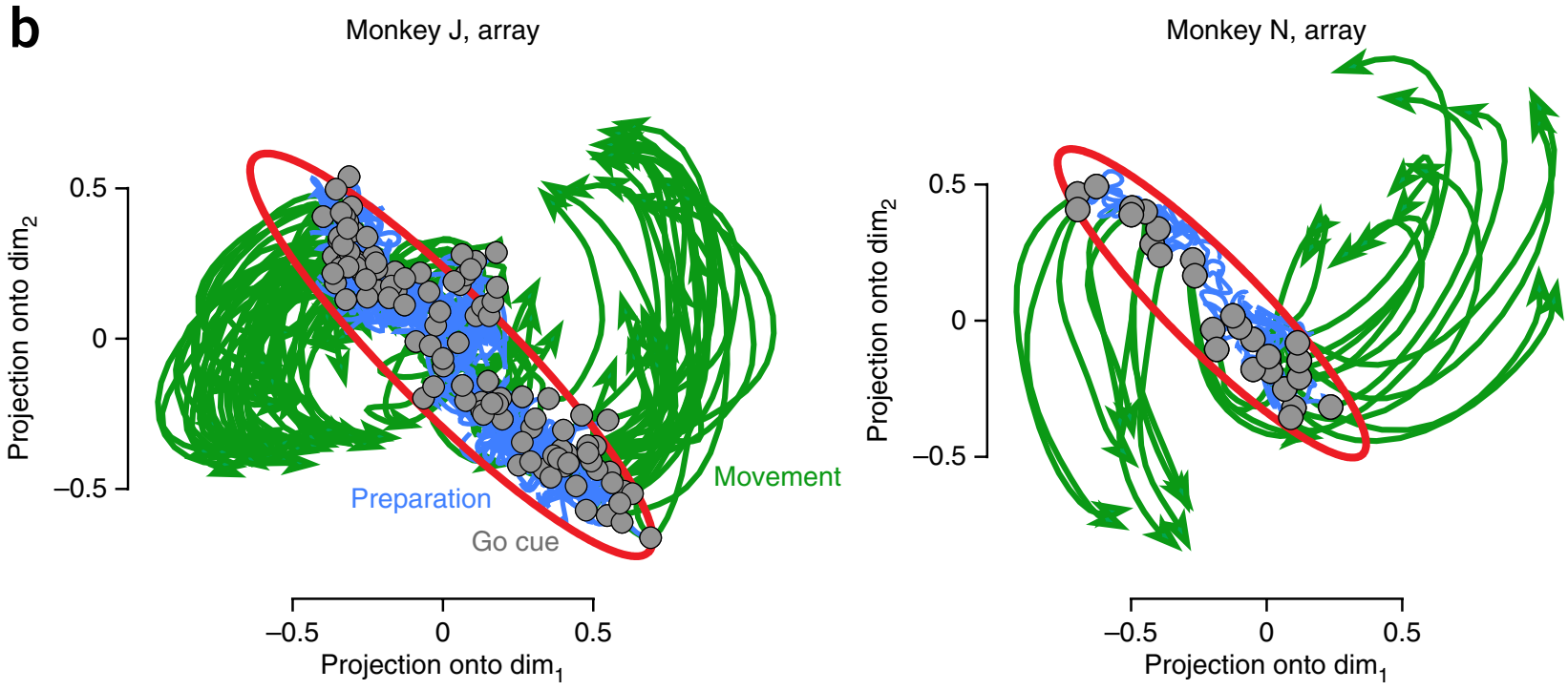
(If you understand this, you understand the entire paper)

Fig 3:

illustrative pair:



population analysis (axes from PCA):



Approach: estimate output-potent (and output-null) dimensions from movement period activity only

$$\hat{W} = \arg\min_{W} ||M - NW||^2$$

via principal components regression (PCR) then look at row space of W^T

(each column of W has weights for a single muscle)

6PCs for N, 3PCs for M,

$\Longrightarrow$ W is 6 x 3

$\Longrightarrow$ 3D "potent" and 3D null space

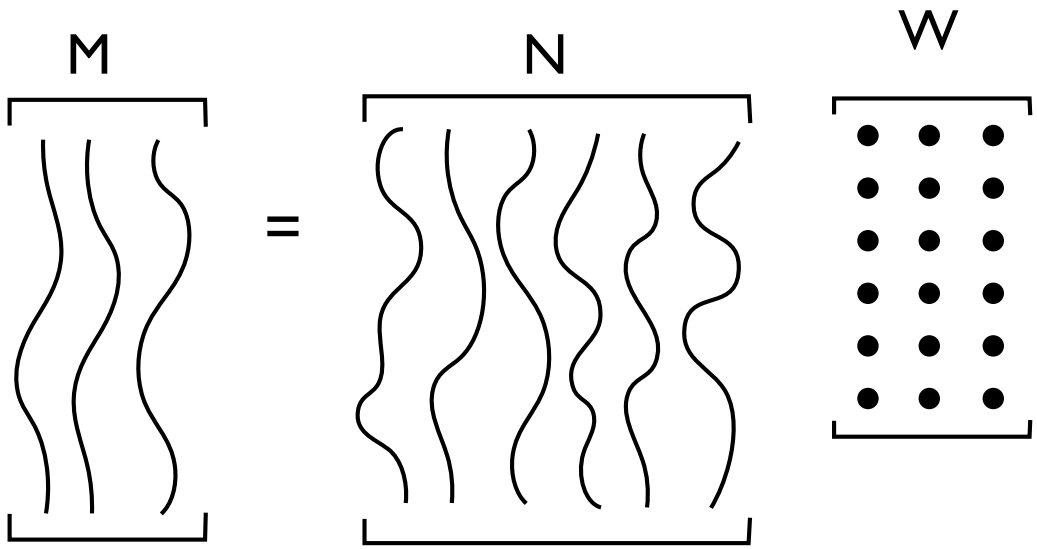
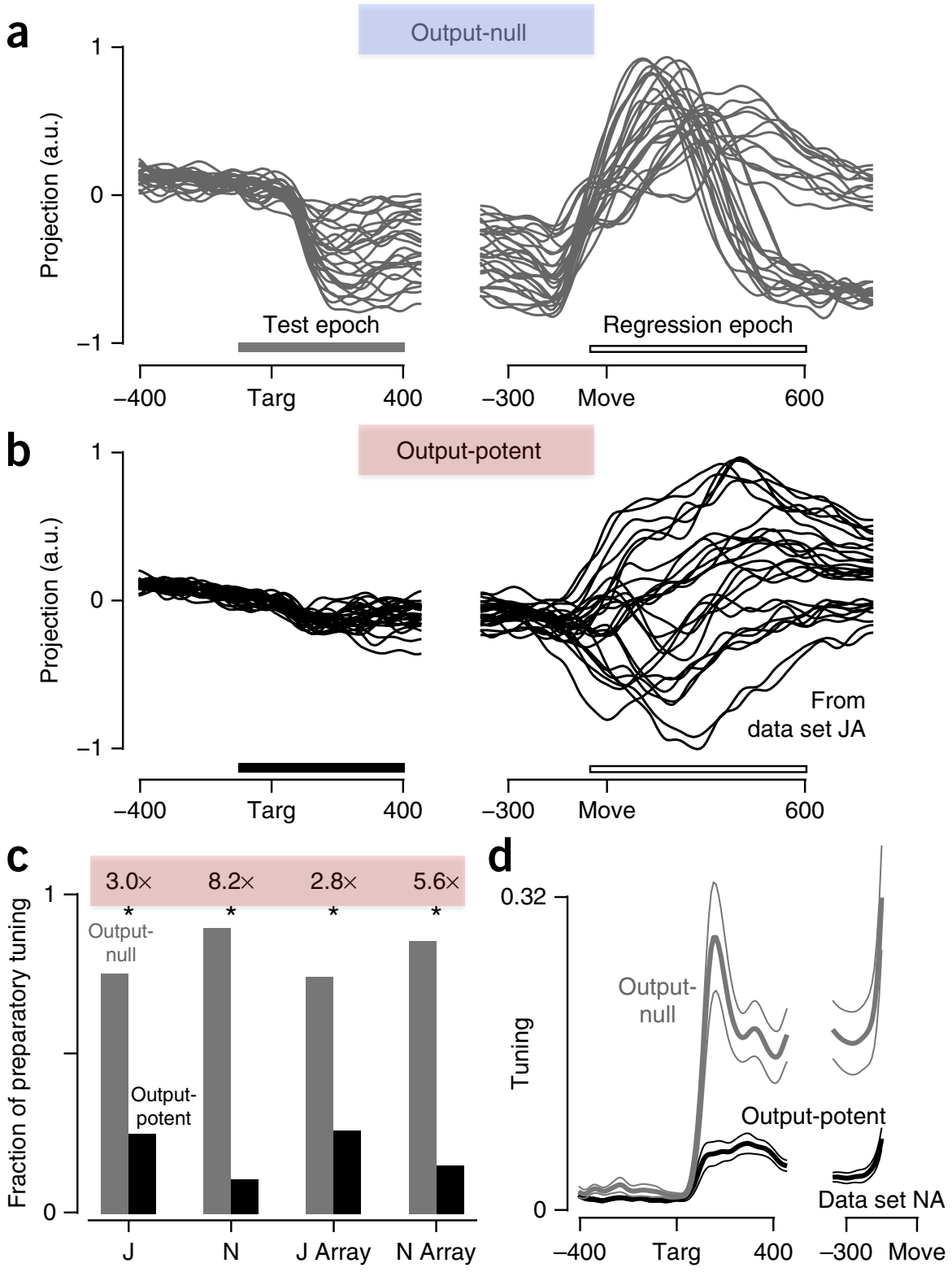


fig 4:

tuning ratio:



Accords nicely with observation that preparatory tuning often uncorrelated with peri-movement tuning

caveat: trial-averaged activity only!

"Trial-averaged data were used except where noted: the primary goal of these analyses was to explain how there can be preparatory tuning without movement, not to explain trial-by-trial variability."

summary

- null spaces: simple reason preparatory neural activity fails to generate movement
  (i.e., muscles add it up in a way that cancels out)
- preparatory PMd activity also lies in null space of weights driving M1 from PMd